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FEBRUARY 1976

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ACN 21646

TR 5-76

TETAM MODEL VERIFICATION STUDY

Volume II

MODIFIED REPRESENTATIONS OF INTERVISIBILITY

Technical Report TR 5-76

AD A024168

UNITED STATES ARMY COMBINED ARMS CENTER

COMBINED ARMS
COMBAT DEVELOPMENTS ACTIVITY

Combat Operations Analysis Directorate

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Technical Report 5-76
February 1976

Directorate of Combat Operations Analysis
US Army Combined Arms Combat Developments Activity
Fort Leavenworth, Kansas 66027

TETAM MODEL VERIFICATION STUDY

Volume II

Modified Representations of Intervisibility

by

MAJ Allan R. Christensen
Mr. Edgar D. Arendt

ACN 21646

Approved by:

David J. Farmer
Chief, Model Support Division

Leland C. Pleger
Technical Director

Reed E. Davis, Jr.
Colonel, IN
Director

ABSTRACT

The TETAM Model Verification study is reported in three volumes describing the validation of three high resolution combat simulation models (DYNTACS, IUA, and CARMONETTE) using field data collected by US Army Combat Developments Experimentation Command during Experiment 11.8. Volumes I and II contain an intervisibility study describing the abilities of the DYNTACS, IUA, and CARMONETTE terrain processors to predict line-of-sight occurrences between tanks and antitank missile positions. Volume III contains a validation study of the engagement processors of DYNTACS and IUA. The results from the simulation models in terms of firings, engagements, and losses between tank and antitank as compared with the field data collected during the free play battles of Field Experiment 11.8 are found in Volume III.

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EXECUTIVE SUMMARY

1. INTRODUCTION. The Tactical Effectiveness Testing of Antitank Missiles (TETAM) program, originated in December 1970 by Department of Defense Program Budget Decision 464, consists of three major elements: a field experiment conducted by Combat Developments Experimentation Command in 1972-73, a detailed evaluation of the effectiveness of US antitank missile weapons based primarily upon data collected during that field experiement, and an evaluation of the predictive abilities of three of the Army's frequently used high resolution simulation models of tank-antitank warfare using the results of the field experiment as a baseline. Progress on this third major element of the TETAM program, the Model Verification Study, is the subject of this report.

2. PURPOSE. The purpose of the Model Verification Study is to determine the ability of the DYNTACS, CARMONETTE, and Individual Unit Action (IUA) high resolution combat simulations to:

a. Predict the outcomes of selected tank-antitank battles conducted (simulated) during the CDEC Experiment 11.8.

b. Represent the major battlefield activities and processes leading to these outcomes.

3. SEQUENTIAL STUDY. Each of the three models is designed to simulate the conduct of tank-antitank battles by playing in detail the fundamental battlefield activities of participating personnel and weapons systems and the environment within which these activities occur. These fundamental activities include but are not limited to the search for, detection, recognition, and identification of targets on the battlefield; the loading, laying, and firing of antitank weapons; and the process of guiding antitank missiles onto their intended targets. For any given weapon crew, these activities often occur in well defined sequences. Within a given sequence, the occurrence of one activity is normally dependent upon the previous occurrence of the preceding activities; and most of these fundamental activities are either directly or indirectly conditional upon the existence of line of sight (intervisibility). A sequential approach to the study was appropriate, and a comprehensive evaluation of each model's ability to represent accurately intervisivility between attacker and defender elements on the battlefield was determined to be a necessary first step in this sequence. Volume I of this study reported the results of the original comparisons of intervisibility as represented in the models and as determined in the field. The major conclusion of these comparisons was that model representation of intervisibility was inadequate and corrective measures would be needed prior to study of other model aspects.

4. OBJECTIVE. The objective of the follow-up intervisibility work was to establish major causes of disagreement between model and field representations of intervisibility and to improve model representation of intervisibility to the extent that it would not seriously bias investigation of other model aspects. Results of this work are reported in this volume of the study report.

5. CONCEPT. The concept for the follow-on intervisibility work was based on the observation that the differences between model and field results must be due to some combination of errors from each of four sources: the field experiment data, model logic, model data, and the original comparison procedures. Based on this observation, the conduct of the field experiment and its resulting data were subjected to a critical review, and comparison procedures were adjusted to account for potential problems in the experimental data. Additionally, model logic and data for DYNTACS and IUA were reviewed, logic problems were identified, and improved data were developed. CARMONETTE was not subjected to the same scrutiny and, while the original CARMONETTE results have been included in this report, the fact that no model or data changes were made for CARMONETTE must be held in mind. In addition to the intervisibility representations of the three combat models, a fourth representation, the WES model, was added to this review. The WES model provides a higher level of terrain resolution than the others and was viewed as a candidate for incorporation into the combat models should it provide an improved representation of intervisibility.

6. REVIEW OF FIELD EXPERIMENT AND COMPARISON PROCEDURES.

a. Based on a comprehensive review of the conduct of the intervisibility portions of Field Experiment 11.8, it was concluded that the field experiment data were of sufficient quality to indicate general levels of intervisibility between the respective defensive areas and areas containing approach paths used in the experiment. The potential for various unchecked and unquantifiable errors in the experiment, however, was judged to be sufficiently large to indicate that comparisons of detailed factors such as the effect of target and observer heights, specific nature of intervisibility interruptions, and occurrence of noninterrupted intervisibility segments would be error prone.

b. Based on the perceived limitations of the experimental data, comparison procedures were revised to place primary emphasis on comparing general levels of intervisibility. While data comparing model behavior with the field on some of the more detailed factors have been included for the sake of completeness, these data have not been given heavy weight in drawing conclusions as to the suitability of model representations.

7. MODEL MODIFICATION AND OPERATION.

a. The most significant modification made to DYNTACS for the intervisibility work was an introduction of stochastic treatment of vegetation. This was indicated by the general nature of the experimental site, which contained numerous stands of large but sparse trees that could not be adequately treated in a deterministic sense. Associated with this change, new input data describing vegetation on the site were developed.

b. The most significant modification made to IUA was a logic change to cause determination of intervisivility to individual defender weapon positions. The original model logic ascribed intervisibility characteristics of each of a limited number of points to several defender weapons. This treatment was clearly incorrect for the experimental site in that it forced the same characteristics to be used for weapons that were both at the foot of and on the crest of a significant ridgeline. Additionally, the IUA terrain data were recorded, using the new DYNTACS data as a guide for placement of vegetation.

c. The revised DYNTACS and IUA models were operated at CACDA by members of the study team. The WES model was operated by its originators at the Waterways Experiment Station and its output forwarded to CACDA for the comparisons. No further operation of CARMONETTE was made in the study with the expiration of the commitment of the proponent agency (Combat Analysis Agency) to support the study.

8. PRINCIPAL FINDINGS. The major results of the comparisons are presented below. It should be noted that, for most models, results differ between the two experimental sites. Site A was dominated by a major ridgeline at and on which the dfender positions were situated. Vegetation on Site A was an important factor at most of the defender positions and at the relatively long attacker ranges but was not significant in the near and mid range areas of attacker advance routes. Site B had no dominating landform, but significant vegetation was spread throughout the site.

a. <u>CARMONETTE</u>. The originally developed CARMONETTE results for Site B were made with terrain data known to be of poor quality and thus provide little indication of model capability. Site A results, considered representative of true model capability, contain a significant overstatement of intervisibility levels for over half of the defensive positions.

b. DYNTACS. Intervisibility levels for Site B are comparably reported by the field and by DYNTACS. Site A results generally contain an acceptable level of agreement although results for certain individual ATM positions are inconsistent. The model appears to have a problem in representing positions on the edge of steep slopes with significant close-in vegetation.

c. IUA. Intervisibility level results produced by the revised IUA for Site A are generally at an acceptable level of agreement with field results. There were, however, a relatively small number of defensive sites for which extreme divergence from the field results was noted. The Site B results for IUA are in serious disagreement with field data.

d. WES Model. Intervisibility levels produced by the WES model for Site A were consistent with field results except in the middle range bands where a potentially severe understatement of intervisibility was noted. WES model results for Site B contain a serious understatement of intervisibility levels when compared to field results.

9. CONCLUSIONS. The following conclusions were reached in the follow-on intervisibility study:

a. The modified intervisibility representations of DYNTACS and IUA are sufficient to allow further TETAM model verification investigations into other model aspects.

b. The CARMONETTE intervisibility representation available for this study is not adequate for further TETAM verification efforts on other model aspects.

c. The WES model does not provide a representation of intervisibility substantially better than that attainable with the combat models.

d. None of the models would provide adequate representation of intervisibility in applications where detailed portrayal of ground truth was critical.

e. The DYNTACS and IUA modifications made for this study are generally appropriate for any application of the models.

CHAPTER 1

INTRODUCTION

1-1. BACKGROUND. The Tactical Effectiveness Testing of Antitank Missiles (TETAM) program was originated in December 1970 by Department of Defense Program Budget Decision 464. As originally defined, the program contained two major elements. Field Experiment 11.8 was conducted by the Combat Developments Experimentation Command (CDEC) in 1972-73 (reference 1). A detailed evaluation of the effectiveness of US antitank missile weapons, based primarily upon data collected during Experiment 11.8, was conducted by the US Army Combined Arms Combat Developments Activity (CACDA) in 1973-1974 (reference 2). In 1972, Department of the Army added a third major element to the TETAM program, that of evaluating the predictive ability of three of the Army's frequently used high resolution simulation models of tank-antitank warfare, using the results of Experiment 11.8 as a basis for evaluation. The resulting Model Verification Study was conducted by CACDA during the period October 1973 to October 1975.

1-2. OVERVIEW OF THE MODEL VERIFICATION STUDY.

a. Purpose and Objectives. The purpose of the Model Verification Study is to determine the ability of the DYNTACS, CARMONETTE, and Individual Unit Action (IUA) high resolution combat simulations to portray the outcomes of selected tank-antitank battles as carried out during CDEC Experiment 11.8 and to represent the major battlefield activities and processes leading to these outcomes. The specific objectives are:

(1) Determine the ability of each model to portray the outcome of Experiment 11.8 tank-antitank battles.

(2) Determine the degree of correlation between Experiment 11.8 and each model in portraying the following aspects of tank-antitank battles:

(a) Attacker-defender intervisibility.

(b) Movement of attacking forces.

(c) Target acquisition.

(d) Target handoff.

(e) Target assignment.

(f) Target engagement/kill.

(g) Combat intelligence.

(h) Communications.

(i) Supporting fires.

(Note: The list of battle aspects to be considered varied during the course of the study. All items shown were identified as candidates for comparisons at one time or another during the study.)

(3) Identify the major underlying assumptions relevant to tank-antitank battles for each model.

(4) Identify and, where possible, prioritize needed modifications and/or improvements for each model.

b. Historical Narrative.

(1) Preliminary stages.

(a) Planning. Responsibility for accomplishing the Model Verification Study was initially assigned to the Systems Analysis Group (SAG) of the US Army Combat Developments Command. SAG had formulated a general approach to the model verification work by March 1973. At that time, as part of the 1973 reorganization of the US Army, responsibility for the study was transferred to CACDA. CACDA expanded this general approach into a specific concept for model verification, which was presented to the TETAM Senior Officer In-Process Review on 20 June 1973 (reference 3). This plan called for a sequential approach to model verification to begin with verification of each model's representation of intervisibility, followed by analysis of each model's play of detection and, finally, by an investigation of the weapon interactions in dynamic, force-on-force, engagements. This approach followed the same general sequence established within the three major phases of CDEC Experiment 11.8. As illustrated in figure 1-1, each step was to involve a comparison of model and field results, determination of sources of observed differences, and corrective actions necessary to continue the process.

(b) Preparation. Of the three models to be evaluated, one (IUA) was the responsibility of CACDA from the outset of the study. Responsibility for a second model (DYNTACS) was transferred from SAG to CACDA in July 1973. This transfer did not include the transfer of personnel familiar with the model, and a program of formal training on the setup and operation of DYNTACS was conducted for CACDA programmers and analysts in November and December 1973 (reference 4). US Army Concepts Analysis Agency (CAA) agreed to operate the third model (CARMONETTE) in support of the model verification work. By mid-January 1974, all three models were being operated in support of the model verification objectives. Detailed intervisibility data collected in the execution of Experiment 11.8 were obtained from CDEC during the last quarter of 1973 and were in a form suitable for the comparisons in January 1974.

(2) Original intervisibility comparisons. The original comparisons of intervisibility data produced by the three models with the Experiment 11.8 intervisibility data were conducted during the period January

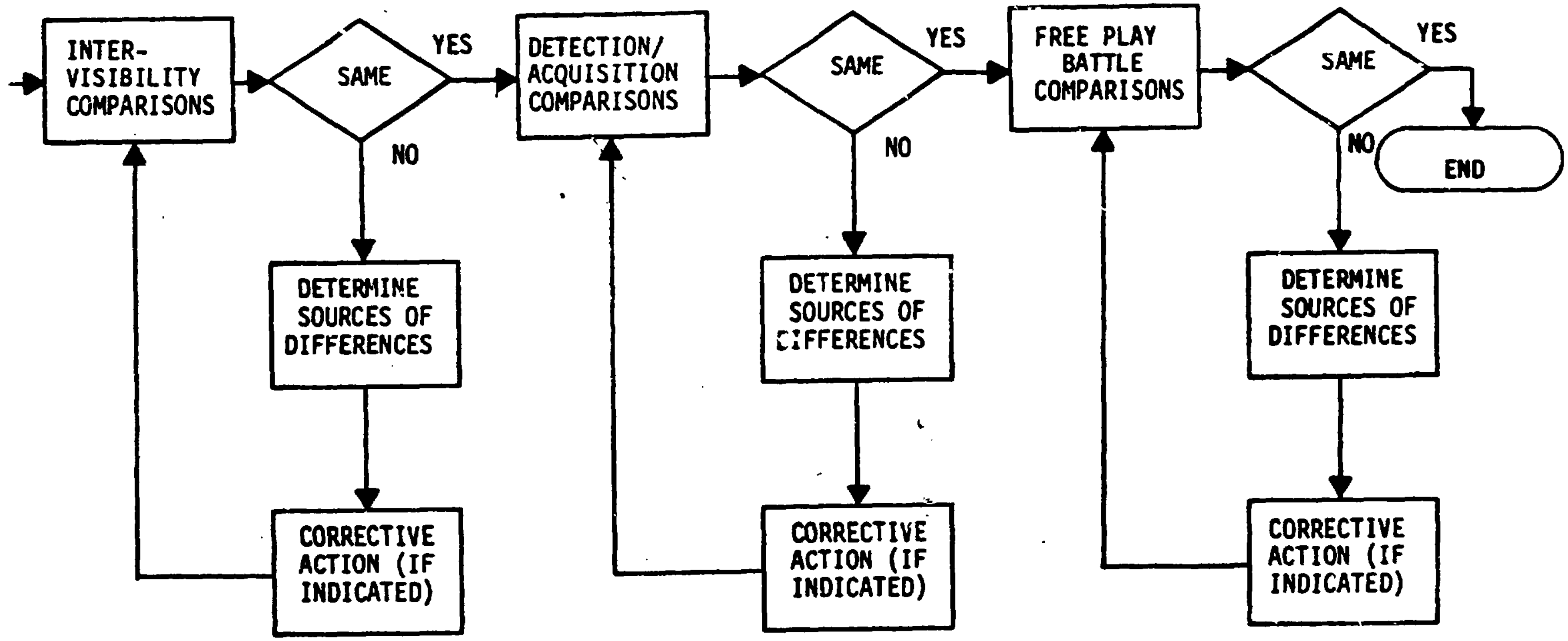


Figure 1-1. Sequential Nature of Model Verification

through May 1974, and an interim report was published in June 1974. The original comparisons were conducted to determine whether the models portrayed intervisibility levels and patterns consistent with those observed in Experiment 11.8. It was anticipated that the level of disagreement between model and field results would be minor and that work could progress into investigations of model representation of detection and battle free play with minimal model adjustments. Contrary to expectations, model results were found to be in serious disagreement with the intervisibility data collected during Experiment 11.8. The original comparisons are contained in a separate volume (reference 5).

(3) Approach revision. The extreme disagreement between model and Experiment 11.8 realizations of intervisibility dictated that further project resources be expended to clarify the causes of this disagreement and to attempt to improve model representation of intervisibility. The study approach was revised to permit continued intervisibility work and, concurrently, to begin the necessary model preparation and field experiment review for the free play comparisons. The study phase dealing with detection as an isolated process was estimated to require a resource increment approximately equal to that already expended on the intervisibility comparisons and was not amenable to initiation until the intervisibility situation had been resolved. Lacking such resources, the detection study phase was dropped from the approach. The revised approach was approved by the Model Verification Study Project Review Board on 15 October 1974. In the interim, the CAA commitment to operate CARMONETTE in support of the study had expired, and the follow-on work was limited to the DYNTACS and IUA models.

(4) Follow-on intervisibility comparisons. The second series of intervisibility comparisons was conducted during the period October 1974 to July 1975, with some preliminary excursions being attempted in August and September 1974. This effort included a critical review of the field experiment as well as significant revisions to the DYNTACS and IUA representations of intervisibility. Additionally, a terrain representation model, which involved a significantly higher level of resolution than that found in the combat simulations, was investigated. This fourth model is a product of the Corps of Engineers Waterways Experiment Station (WES) and was operated by WES in support of the study. The follow-on intervisibility work resulted in representations of intervisibility within DYNTACS and IUA that were judged to be in sufficient agreement with the Experiment 11.8 data to allow the study to progress into the dynamic battle comparisons. The follow-on comparisons and supporting work are documented in this report.

(5) Dynamic battle comparisons. Preliminary work and actual comparisons of dynamic force-on-force battles as represented in IUA and DYNTACS and as carried out in Experiment 11.8 took place during the period November 1974 to September 1975. A significant portion of this effort involved a review of the experimental procedures and data. This review was required

to develop an appreciation of what actually took place in the free play trials of Experiment 11.8. This review and a comparison of model and field results for selected battles, as well as a critical review of model aspects for which no comparison data from Experiment 11.8 were available, are reported as the dynamic battle, or "free play" portion of the Model Verification Study (reference 6).

1-3. PURPOSE AND SCOPE OF REPORT. This report presents the results of the follow-on intervisibility comparisons conducted as part of the TETAM Model Verification Study with supporting background material. Comparisons of intervisibility representation in the IUA and DYNTACS combat models, as revised within this study effort, as well as the representation produced by the WES terrain model, are made with Experiment 11.8 data. Intervisibility results of the original CARMONETTE combat model are included for the sake of completeness, but no attempt was made to adjust this model for the problems found in the original intervisibility comparisons.

1-4. OVERVIEW AND REPORT ORGANIZATION.

a. Study Requirement. Within the context of small unit tank-antitank battles, the existence of intervisibility between a weapon and its potential target is a logical prerequisite to target detection and engagement. The major conclusion of the original set of intervisibility comparisons conducted for the TETAM Model Verification Study (reference 5) was that intervisibility as portrayed in the combat simulations was in serious disagreement with intervisibility data collected in the field during the conduct of CDEC Experiment 11.8. The value of progressing into an attempt to compare model representation of such actions as target acquisition and engagement with the Experiment 11.8 results was questionable, given the knowledge that model representation of a logical precursor to such actions was faulty. Thus, it was necessary to explain the disagreement between model and field intervisibility results and to attempt to bring these results into closer agreement.

b. Purpose. The follow-on intervisibility comparisons and supporting work were conducted to determine the causes of disagreement between model and field realizations of intervisibility and, if appropriate, to make the model modifications needed to attain model results in sufficient agreement with the field data to permit continued model verification effort in such areas as target acquisition and engagement.

c. Approach. The approach to follow-on intervisibility comparisons was based on the observation that the observed disagreement between field and model results must be due to some combination of errors in the field data; errors in model logic, data, or operations; and poor formulation of the approach used in making the original comparisons. Thus, the work had to center upon these three areas; and each were subjected to critical review.

(1) Field experiment data. The intervisibility portions of CDEC Experiment 11.8 provided the baseline for intervisibility comparisons. Error in this field data would have an obvious invalidating effect on the comparison effort. The experimental procedures therefore were subjected to a critical review to identify and assess the extent of potential for error in these data. This review is contained in chapter 2. In addition to the independent review by CACDA, CDEC was requested, as the data originator, to investigate the potential for error in position measurement and in the inclusion of target detection as an uncontrolled factor in the experiment. CDEC was also requested to review the quality control data collected in the trial, since these data constituted the only replication in the experiment, to identify predominant observer error modes or patterns. Due to the time lag between the execution of the experiment and this request (2 years) and due to the CDEC workload, CDEC was unable to accommodate the study team in this request beyond restating that all reasonable care had been taken in the conduct of the experiment.

(2) Model review and operation.

(a) The results of the original intervisibility comparisons indicated that, while field data and comparison approach errors may have been contributory factors, the greatest part of the model and field data disagreement was attributable to faults in model representation. The following actions were taken to resolve this problem area:

1. The Corps of Engineers Waterways Experiment Station (WES) was requested to produce intervisibility data for the same experimental conditions as portrayed in the combat simulations, using a model available at WES. The WES model is a specialized terrain model at a more detailed level of resolution than used in the combat simulation representations of terrain. The WES model was a candidate for wholesale incorporation into one or more of the combat simulations should it prove capable of a significantly better representation of terrain than that found in the combat simulations.

2. A series of exploratory changes were made to the DYNTACS logic and terrain descriptive data. These excursions were not made with a well defined run plan, and their results were reviewed only in the pragmatic sense of whether they moved the general DYNTACS results into closer consonance with the field data. This situation was due both to a state of staffing flux at this point in the study as well as to an inability to test specific hypotheses as to the location of masks in the field, since the field data did not provide such information. These excursions led to the impression that DYNTACS treatment of vegetation was the most important contributor to model and field result disagreement and thus indicated the general nature of the change to be made to the DYNTACS logic and data.

3. Revisions to the IUA model logic and data were made. These revisions had been indicated both in the side analysis conducted as part of the original comparisons and as a result of the DYNTACS modifications.

(b) The revised DYNTACS and IUA models, as well as the WES model, were then operated over the set of Experiment 11.8 conditions to provide intervisibility data for the comparisons. Logic of the various models used in producing these data is discussed in chapter 3. Additionally, the original DYNTACS, IUA, and CARMONETTE logic is presented.

(3) Comparison approach. The measures used in the follow-on intervisibility comparisons and the nature of comparisons made are introduced in chapter 4. The follow-on comparisons were carried out with a less critical philosophy than was found in the original comparisons. Significant aspects of this change include:

(a) Comparisons are generally based on probability of line of sight; i.e., intervisibility levels, between various portions of the field. The use of intervisibility segments as a comparison variable is deemphasized because of an apparent extreme sensitivity of segment-oriented variables to minor levels of error in the data.

(b) Tests of the statistical significance of differences are not reported and, in general, were not conducted. Rather, levels of acceptable agreement were judgmentally set and adhered to. Attempts were made to provide sufficient information to allow the individual reader to establish his own levels of acceptance and arrive at his individual conclusions.

d. Results. Results of the basic comparisons are presented in chapter 5, and several side comparisons are presented in chapter 6. In selected cases, results of the original as well as the improved DYNTACS and IUA model versions are presented. This is needed to insure that any improved agreement between model and field results is related to the model changes rather than simply to the fact that the comparison approach is less critical than that originally used. Interpretations by the study team and conclusions are found in chapter 8. The reader should remember that where these results and conclusions bear upon the CARMONETTE model, the original model results are used. It is possible that relatively minor CARMONETTE model or data changes could produce a level of agreement with field results comparable to that gained with the revised DYNTACS or IUA.

CHAPTER 2

THE INTERVISIBILITY FIELD EXPERIMENT

2-1. GENERAL. One of the objectives of CDEC Experiment 11.8 was to collect data suitable for use in model verification. Thus, detailed intervisibility data were available from the field experiment for use as a standard against which to evaluate model performance.

a. Phase I, CDEC Experiment 11.8 was conducted during the period March-December 1972 to collect data on the frequency and duration of intervisibility between defensively emplaced antitank missile weapons and advancing enemy armored vehicles. These data were collected on 12 sites in West Germany, 2 sites at Fort Lewis, Washington and 2 sites at Hunter-Liggett Military Reservation (HLMR), California. Since the other phases of Experiment 11.8 to be used in model verification were conducted at Hunter-Liggett, the HLMR data were used for intervisibility comparisons.

b. A detailed description of the intervisibility field experiment and an analysis of the resulting data is contained in the CDEC report (reference 1d) and is not repeated here. However, a working knowledge of the experiment and of the nature of data collected during the experiment is necessary to appreciate the approach taken in model comparisons and the results of those comparisons. Therefore, a summary of those aspects relevant to the model verifications work follows.

2-2. CONDUCT OF THE FIELD EXPERIMENT. Phase IA (Intervisibility) of Experiment 11.8 was conducted in September and October 1972 at the Hunter-Liggett Military Reservation, California.

a. <u>Experimentation Sites</u>. Intervisibility data were collected on two 2x5 kilometer terrain sites. The sites were located within the same valley, and were partially overlapping, but their general characteristics were distinctly different.

(1) Site A was dominated by a ridge 100 meters higher than the valley floor, with defensive positions located on the top, forward slopes, and in front of this ridge. A relatively thick growth of trees was present over the ridge. Scattered oak trees, approximately 20 meters high, were found in the valley floor, increasing in density at greater ranges from the dominating ridge.

(2) Site B was located entirely on the valley floor, with the defensive positions only slightly higher than enemy avenues of approach. Trees scattered throughout the site had a pronounced effect on observation and fields of fire.

b. Defender (ATM) Positions. Thirty-six positions suitable for use as antitank missile emplacements were selected within the respective defensive areas of each site. Large tri-colored panels were erected at each position. The panels had three horizontal color bands representing the heights of the M551, the M113-mounted TOW, and the ground mounted TOW (or DRAGON).

c. Attacker Routes. On each site, 10 attacker approach routes were established such that each route represented a tactically realistic approach for armored vehicles assigned the mission of closing with the defensive position as rapidly as possible. An additional set of 10 routes was established on Site A in order to collect intervisibility data for a situation in which the attacking force would attempt to take maximum advantage of available cover and concealment en route to the objective. The three resulting sets of intervisibility data generally are treated independently in this analysis and are referred to as Site A-Rapid Approach, Site A-Covered and Concealed Approach, and Site B.

d. Measurement Interval. Specific points from which intervisibility data were to be collected were established at intervals of approximately 25 meters along each approach route. These viewing points were marked with stakes driven into the ground and for convenience are referred to as "stakes" throughout this report.

e. Height Combinations. At each stake, data collection teams made intervisibility observations from two different heights intended to represent the height of the driver of a threat tank and the highest point on a threat ATGM vehicle. When combined with the three heights of the tri-colored target panels, these observations provide data for six target/observer height combinations.

f. Data Collection Procedures. Two types of data were collected: the UTM coordinates of observer stakes and target panels and the actual intervisibility determinations.

(1) Position survey. The locations (UTM coordinates) of each target panel and of selected observer stakes were determined using the Range Measuring System (RMS) available at HLMR. Observer stake locations were determined for essentially half (generally the odd numbered stakes) of the Site B and the Site A-Rapid Approach trials. Almost all stakes were surveyed for the Site A-C&C Approach trial. The RMS is an automated range measuring and location determination system that operates on the basis of ranges (determined by transmission response times) between a transponder located at the position to be surveyed and a number of stations for which locations are known. Further details concerning the RMS may be found in CDEC documentation.

(2) Intervisibility determinations. Intervisibility data were collected by two-man teams. At each stake, one team member visually determined the lowest color band visible (if any) of each target panel and, where a panel was totally or partially blocked, reported the nature of the blockage as being landform, vegetation, cultural, or unknown. The other team member recorded these determinations on specially labled data processing cards using "Port-a-Punch" cards and a template. Two cards (one for each observer height) were produced for each stake. In addition to the cards and punching equipment, each team was provided with a 6-foot stepladder, used to attain both the high observer height (9 feet 4 inches) and, by means of a marked step, the low observer height (4 feet). Each team was also provided with a telescope and binoculars, either or neither of which could be used at the observer's discretion, and an annotated photograph to assist in locating and identifying the target panels. Each team was responsible for making determinations for approximately 80 consecutive stakes, beginning at the assigned stake nearest the defensive position and proceeding sequentially along the assigned path moving away from the target panels.

2-3. RESULTING DATA BASE.

a. The raw data collected in the field has been incorporated by CDEC into a data base, available on magnetic tape, suitable for automated processing. This automated data base includes the UTM coordinates of each panel, UTM coordinates of the selected stakes on each approach route, and the set of intervisibility determinations for each stake.

b. Data within the automated CDEC data base are maintained in a highly compacted form. To facilitate its use in comparisons with the model results, the original data base provided by CDEC was reformatted. During this process, a few anomalous data entries were identified and the necessary resolutions made. The effort involved and procedures followed are discussed in the report for the first phase intervisibility comparisons (reference 5).

2-4. REPORTED QUALITY OF DATA.

a. Intervisibility Determinations. In reference to the intervisibility determination data, the CDEC final report states that "at the very worst, 5.0 percent of the data could be in error." This estimate is based on the verification procedures followed in the conduct of the experiment, documented in the CDEC final report (reference 1d, appendix A) and summarized below:

(1) Overlap. Three teams were assigned to collect data on each of the 10 paths. Each team was responsible for more than one-third of its assigned path, giving an overlap region of 21 stakes between each pair of adjacent data collection teams and providing two full sets of intervisibility data for 42 of the stakes on each path.

(2) Spot Check. An additional check on the data was provided by number of spot checks. Each of five spot check teams collected line-of-sight (LOS) data at eight consecutive stakes on each of the 10 paths, thus providing 40 "spot checked" stakes per path. These teams were instructed to concentrate their efforts on portions of the paths where intervisibility existed. Spot check teams collected data only as to the existence or nonexistence of line of sight and only from the high observer height.

(3) Error definition. An "error" was said to exist if a pair of LOS determinations from a given stake to a given panel differed by two or more panel color bands. Missing data were also considered an error. This error determination was made only for the high observer height. The reported type of obstruction, if any, was not considered in error determination.

(4) Acceptance criterion. The data from a team's path segment were considered acceptable if the percentage error for that team's double-checked stakes did not exceed 5 percent, where percent error was defined as:

$$\text{Percent error} = \frac{\text{number of errors}}{\text{number of targets (36)} \times \text{number of double-checked stakes}}$$

(5) Remeasurement. Given lack of acceptance, remeasurement was indicated. Procedures for deciding what was to be remeasured are documented in the CDEC report as follows: "The first step in determining which path segments or paths required remeasurement was to examine the percent error of each overlap region. Path overlap regions with percent errors less than 5.0 percent were considered valid, not requiring remeasurement. When the error from the overlap region was equal to or greater than 5.0 percent, the data from the spot check teams was used in an attempt to determine which team was responsible for the failure. If the overlap failure could be ascribed as being due to a particular team, only the stakes of that team were assigned to be remeasured. If it could not be determined which team was causing the overlap failure, then both teams' portions of the path were remeasured." (reference 1d, page A-1-13)

b. <u>Location Measurements</u>. The CDEC report states that "the RMS instrumentation used in the point location survey provided an accuracy of ± 5 meters on the X and Y coordinate location for each measured point." This is assumed to be based on system specifications and/or CDEC experience with the system.

2-5. REASSESSMENT OF DATA.

a. Requirement. In the planning and execution of a field experiment, it is incumbent upon CDEC to insure that the experiment provides the most accurate and valid data practical within resource constraints. In applying these data, it is no less incumbent upon the user to review the experiment in light of his anticipated use of the data. The user's independent assessment of such data is an essential step in determining how the data are to be applied and the strength with which he may draw conclusions based upon the data. In fulfilling his obligation to make an independent review, the user must assume that the original experimenter was working under some constraints and that sources of error could have crept into the experiment. In this light, the areas presented below appear to have some bearing on the applicability of the field experiment data to the model validation problem.

b. Potential Errors.

(1) Target detection. To measure the existence of intervisibility, an individual had the task of visually scanning a target area, approximately 1,500 meters in width, and reporting which of 36 available target panels he could see. Clearly, this is not the same target search process involved in an operationally realistic situation; it is inescapable, however, that the individual data collector was performing a task of target detection.

(a) In the planning for and execution of the field experiment, efforts were made to minimize the influence of detection problems on experimental results. These included such procedures as the use of large size ATM panels, the use of contrasting colors on the panels, testing data collectors for color blindness, equipping the data collectors with binoculars and scopes, arranging the panel identifications in a specified order so observers knew if a panel was skipped, providing observers with a photograph of the target area indicating relative panel locations, having data collectors begin their tasks at the portion of their assigned path nearest the targets, delaying observations until atmospheric conditions were favorable, and, of course, the provision of duplicate measures made in overlap and spot check areas for the validation process.

(b) Certain uncontrolled factors remain in the experiment. While in most cases unavoidable, their presence must be considered in light of their potential impact on the results. Some of these factors are:

1 The use of optical aids was left to the discretion of the individual observer.

2 Observer-to-target ranges went to beyond 5 kilometers. At these ranges, visual detection could be a problem even with optical aids and prior knowledge of target location.

3 Site A target panels are on the northern face of a ridgeline running in an east-to-west direction, and observers were generally looking in a southeasterly direction. As would be expected in September, the sun was in an unfavorable position during the morning hour , and trials had to be postponed until 1400 hours. Considering the orientation of the ridge and the season, it is possible that lighting and shadow conditions were poor for some of the panels throughout the day and affected their detectability.

4 The requirement for observations from a height of 9 feet 4 inches and 4 feet forced some inconvenience on the observer in attaining proper positions for observation. The higher height was to be attained through use of a support for the observer's optical aid (assuming he used an aid) attached to his stepladder. The lower height corresponded to a step on the ladder. The consistency with which these heights were attained is unknown.

5 The diligence with which an individual performed the detection task was related to his motivation at the inception of the task and ensuing boredom or fatigue with the task, if any. Such factors are universal in experimentation with human subjects; and, having done what is possible to control them, the experimenter must reconcile himself to accepting their residual effects, which are generally unknown.

(c) It is impossible to state the extent to which any of the above factors entered into the experiment. To the extent that such factors had an influence on the experiment, their net result would have been to decrease the reported level of intervisibility below that which actually existed; these factors would generally lead to isolated instances in which an observer failed to detect a target panel that was visible. An exception might be expected in the case where a higher viewing position than prescribed was attained, which could have occurred occasionally, particularly from the low observer position. Errors introduced by a deterioration in observer motivation would result in less diligent performance, thus "missing" occasional targets, more frequently than in the interjection of a spurious sighting, which would call for an intentional effort to err.

(2) Judgmental or perception errors. Given a decision that he could or could not see an individual target panel, the observer had to establish the lowest visible color band of the target and the nature of the intervening blockage, if any. Three potential errors of a perceptive or judgmental nature are involved:

(a) Target identification. The observer had to specify which target he could see. To facilitate this, each panel had a white identifying numeral or letter painted in the upper color band. The observer also had his photograph of the defensive area to assist in

locating individual panels. It is reasonable to assume that the number of misidentification errors was minimal. It is equally reasonable to assume, for example, that in the course of almost 21,000 reported target sightings from the high observer position on Site A rapid approach, occasional misidentification errors were made.

(b) Portions visible. Given that a target panel was visible, the observer was to report the lowest visible color band. An analysis of the potential errors in this discrimination would involve a complex study of visual perception, complicated by the effects of atmospheric conditions at extended ranges and further confounded by potential minor errors in maintaining consistent observer heights. For the purpose of this study it is sufficient to consider this as an observer judgment factor. A moderate, and potentially significant, number of errors in making this judgment are assumed to have taken place. No means to support or to refute this assumption, short of additional experimentation, are known.

(c) Nature of interruption. Given complete or partial blockage of a target panel, the observer reported the nature of the interruption as being landform, vegetation, cultural (man-made) or unknown. This again is an observer judgment. The determination is assumed relatively error free where partial blockage of the target exists, since in this case the observer should be able to observe directly what is blocking the portion of the target he cannot see. Where none of the target can be seen, determination of the mask should be relatively free of error when the mask is near to the observer, since he then knows that this near-in mask blocks his view in the general direction of the target. Lacking a close-in mask, the observer must estimate the exact position of an invisible target and decide what, in that line of sight, blocks his view. This is an error-prone process, but there is nothing in the data to allow discrimination between the relatively error-free and the error-prone cases when the target is fully blocked.

(3) Transcription errors. Observations were manually recorded on a punch card for each observer height at each stake. For each collection team, this amounts to making up to 72 entries on each of approximately 160 cards. It is assumed that the number of transcription errors involved in punching these cards was minimal, but it is assumed that occasional errors did occur. No analysis of errors of this nature is available, and it is assumed that the results would enter the data base in an unpredictable fashion, with occasional determinations being misrecorded and, perhaps, with the wrong card (resulting in the determinations being recorded for the wrong stake and/or observer height) occasionally having been used.

(4) Instrumentation accuracy. The survey locations of target panels and selected path stakes are reported as having ± 5 meters error in the X and Y coordinates of each point, based on the accuracy of the Range Measuring System (RMS) instrumentation used to obtain the data. Locations are determined by measuring range, as determined by transmission delay times, to a number of known positions (A-stations) and computing X, Y, and Z coordinates. Accuracy, then, must be a function of the number and relative positions of A-stations, as well as the accuracy to which their positions are known, and would be expected to vary over the experimentation site. In the absence of information to the contrary, it is assumed that the reported ± 5 meter error is based on hardware specifications and represents "typical" system inaccuracy. The typical error inherent in the Experiment 11.8 location data must then be accepted as being of this approximate size (± 5 meters in X and Y) but not necessarily limited to this size; i.e., occasional larger errors are to be expected.

c. <u>Validation Procedures</u>. The validation procedures followed in the intervisibility portion of Experiment 11.8 appear to have been a reasonable attempt to keep the most serious errors in LOS determination at a low level. There are, however, several limitations to the procedures.

(1) Checks were only made for the high observer position, and only discrepancies of at least two color bands were considered in error. Thus, differences in the nature of an interruption of intervisibility and differences in the amount of a panel visible within one color band were not considered as errors, and no checks on the low observer height were made.

(2) The procedure was oriented toward, and remeasurement criteria based on, identifying those data collection teams that were consistently inaccurate and remeasuring the data required of those teams. Occasional errors appear to have been accepted as long as the team was not systematically bad in its observations.

(3) Although error, as defined by the validation procedure, was controlled, the statistical basis for claiming no more than 5 percent (or any quantified amount of the data) to be in error is not substantiated.

d. <u>Conclusions</u>. Based on the perceived potential for error in the field data and consideration of the reported quality control procedures, the following conclusions as to the utilization of these data as a basis of comparisons for model verification have been drawn.

(1) The data collected in Experiment 11.8 are of sufficient quality to indicate the general levels of intervisibility between the respective defensive areas and the areas containing the approach paths.

(2) Since only data for high observer positions were subject to data validation and since the validation procedures only considered large discrepancies (two color bands) in target height to indicate error, inferences regarding the effects of target/observer height differences on intervisibility should be made with caution.

(3) Since no consistency checks were made on the data recording nature of LOS interruptions, inferences concerning this portion of the data should be limited to those of a general nature.

(4) Given the potential for detection errors, if there is a consistent error in the Experiment 11.8 data, it would tend to be an understatement of intervisibility, particularly at longer ranges.

(5) Given the potential for random error throughout the intervisibility data and the uncertainty in accuracy of the location data, analyses that depend upon the results for specific points must be approached with caution. This includes any analyses attempting to identify segments of uninterrupted intervisibility or lack thereof.

(6) There is no apparent basis for the quantification of error rates or of a statistical level of confidence to be ascribed to the basic data.

CHAPTER 3

INTERVISIBILITY MODELS

1. GENERAL. The portrayal of intervisibility, as accomplished by each of four models (CARMONETTE, DYNTACS, IUA, and the WES model), was compared to the realizations of intervisibility contained in the Experiment 11.8 data base. This chapter introduces the approach to representing intervisibility found in each of the models and the modifications made to DYNTACS and IUA model logic to produce a more reasonable approximation of the Experiment 11.8 outcomes. This chapter provides sufficient information for comprehension of the results obtained and work performed in the intervisibility comparisons. Documentation of the individual models in full detail has not been attempted, and the interested reader may refer to the model documentation volumes identified in the bibliography at appendix A for further details of the original models and the programer notes at appendix C for further detail of modifications made in the course of this study.

3-2. FUNDAMENTAL INTERVISIBILITY MODEL. Each of the models investigated uses a similar fundamental approach in representing intervisibility. Significant differences, however, are found in the individual implementations of this approach, the levels of detail attempted, and additional elaborations contained within each model. The fundamental model approach is described below, followed by a discussion of its implementation within each model.

a. A system of regular geometric shapes, covering the battlefield, is developed as the basis for terrain representation. A square grid system is used in CARMONETTE and the WES model, a system of variable sized (and shaped) contiguous triangles is used in IUA, and a combination of the square grid system with overlayed circles and parallelograms is used in DYNTACS.

b. Landform is described by assigning surface elevations to these geometric shapes. For CARMONETTE, an average elevation is assigned to each grid square or "terrain cell." This elevation then applies throughout the cell. For IUA, an elevation is provided for each triangle vertex, allowing each triangle face to be treated as a plane surface and permitting calculation of surface elevation at any point on the plane by interpolation. For DYNTACS, an elevation is provided for each grid line intersection within the square grid system, and each grid square is then divided into two right triangles (defined by the negative-slope diagonal through each cell). Each resulting triangle face is treated as a plane surface, as with IUA. The WES model also represents the terrain surface by interpolation on grid elevations. This representation, however, uses a quadratic interpolation scheme with four grid points rather than the linear interpolation on three points used by IUA or DYNTACS. The resulting surface is more complex and, potentially, more accurate than the plane surface representation of the other models.

c. Significant vegetation is described in CARMONETTE and the WES model by assigning an average vegetation height to each grid square and, for IUA, by assigning a vegetation height to each triangle. DYNTACS allows the development of an arbitrary number of circles and parallelograms, independent of the elevation grid system, each of which contains significant vegetation. A single vegetation height is then applied to all of these circular and parallelogram DYNTACS forest features. Significant vegetation is treated as being opaque for intervisibility purposes; thus, the data conceivably could be used to represent different blockages to intervisibility such as built-up areas or other significant man-made features.

d. The determination of whether intervisibility exists between two points is made by a simple application of plane geometry. The points in question define a straight line in 3-space, the line of sight (LOS). The LOS and its projection on the horizontal (X-Y) plane define a normal vertical (Z) plane. A terrain profile is developed in this vertical plane, using the terrain elevation plus "significant vegetation" height (if any) associated with selected points along the horizontal projection of the LOS (i.e., at selected X-Y coordinates). If the LOS is not interrupted by the terrain profile, intervisibility is said to exist; otherwise, intervisibility does not exist. To check for LOS interruption, the height of the LOS is compared to the terrain profile height at each of the selected profile points (or a geometrically equivalent comparison is made), and interruption occurs if the profile is higher than the LOS. Implementation differs among the models primarily in selection of the points used to define an intervening terrain profile. Each approach depends on the specific model's terrain representation.

e. The fundamental intervisibility approach, as implemented in each model, is oriented toward the determination of LOS blockage intervening between points. Possible cover and concealment in the immediate vicinity of the target or observer, where the definition of "immediate vicinity" may vary from model to model and from case to case in a given model, tend to be treated separately from the intervisibility determinations, typically within the target detection (for concealment) and target assessment or firing (for cover) logic of the respective models.

3-3. CARMONETTE INTERVISIBILITY.

a. Terrain Representation. CARMONETTE terrain representation is tied to a 60 by 63 array of equally sized square grid cells. Cell size is a variable. For TETAM applications a 100-meter cell was used, dictated primarily by the overall size of the terrain sites under consideration. Terrain characteristics involved in intervisibility are the average elevation and average vegetation heights assigned to each grid square. Additionally four indexes are assigned to each cell representing cross-country trafficability, road trafficability, concealment, and cover. Terrain characteristics apply uniformly within a given terrain cell to any unit within the cell. In fact, unit locations are resolved only to the terrain cell level, with exact position within a cell unspecified.

b. Intervisibility Calculations. CARMONETTE intervisibility calculations use the center of terrain cells only. The line of sight between two units is computed between the centers of the terrain cells occupied by the two units. The height of an LOS endpoint is defined as the elevation of the respective terrain cell plus "sensor height" of the unit in question. The same height is used regardless of whether the unit is observer or target, resulting in an "eyeball-to-eyeball" LOS determination. Selection of points to describe the intervening terrain profile depends upon relative position of the units in question. If the LOS is parallel to or at a 45° angle to the cell boundaries, the LOS projection in the X-Y plane will pass through the center of each intervening cell (LOS endpoints being at cell centers). In this case, the intervening profile is determined by cell elevation plus vegetation height at each of these intervening cell centers. Where the LOS does not line up with cell boundaries or diagonals, the LOS is approximated by a "staircase" made up of line segments that are either parallel to or on the diagonals of terrain cells as illustrated in figure 3-1. Each of these segments begins at a terrain cell center and ends at a laterally or diagonally adjacent cell center. Cell centers connected by the pseudo-LOS are then used to define the terrain profile used in the basic intervisibility test.

c. Additional Factors.

(1) Should the two units for which intervisibility is in question be in the same or adjacent (laterally or diagonally) terrain cells, it is impossible to define an intervening terrain profile because there are no intervening terrain cell centers. In this case, CARMONETTE assumes the existence of intervisibility between the units in question.

(2) In addition to the basic intervisibility calculations, CARMONETTE detection logic uses the concealment index of a potential target's terrain cell to reduce the effective target size used in detection calculations.

3-4. IUA INTERVISIBILITY. The intervisibility calculations made for IUA are similar to those of the other models. IUA, however, differs from the other combat simulations in that intervisibility and movement for IUA are established by preprocessors, the deterministic results of which are then fed to a firepower-oriented "battle model," which contains the Monte Carlo portions of the model allowing for replication. While the actual intervisibility calculations in the IUA preprocessor are typical, there are some potentially severe limitations in their relation to the overall model as discussed below.

a. Terrain Representation. Terrain representation is accomplished in IUA with the "variable triangle" method. In this approach, triangles of varying size are fitted together with common legs and vertices to cover the terrain surface. Surface elevations are assigned to each vertex, and the face of each triangle thus defines an area of constant slope. A vegetation height may also be provided for each triangle. Since the

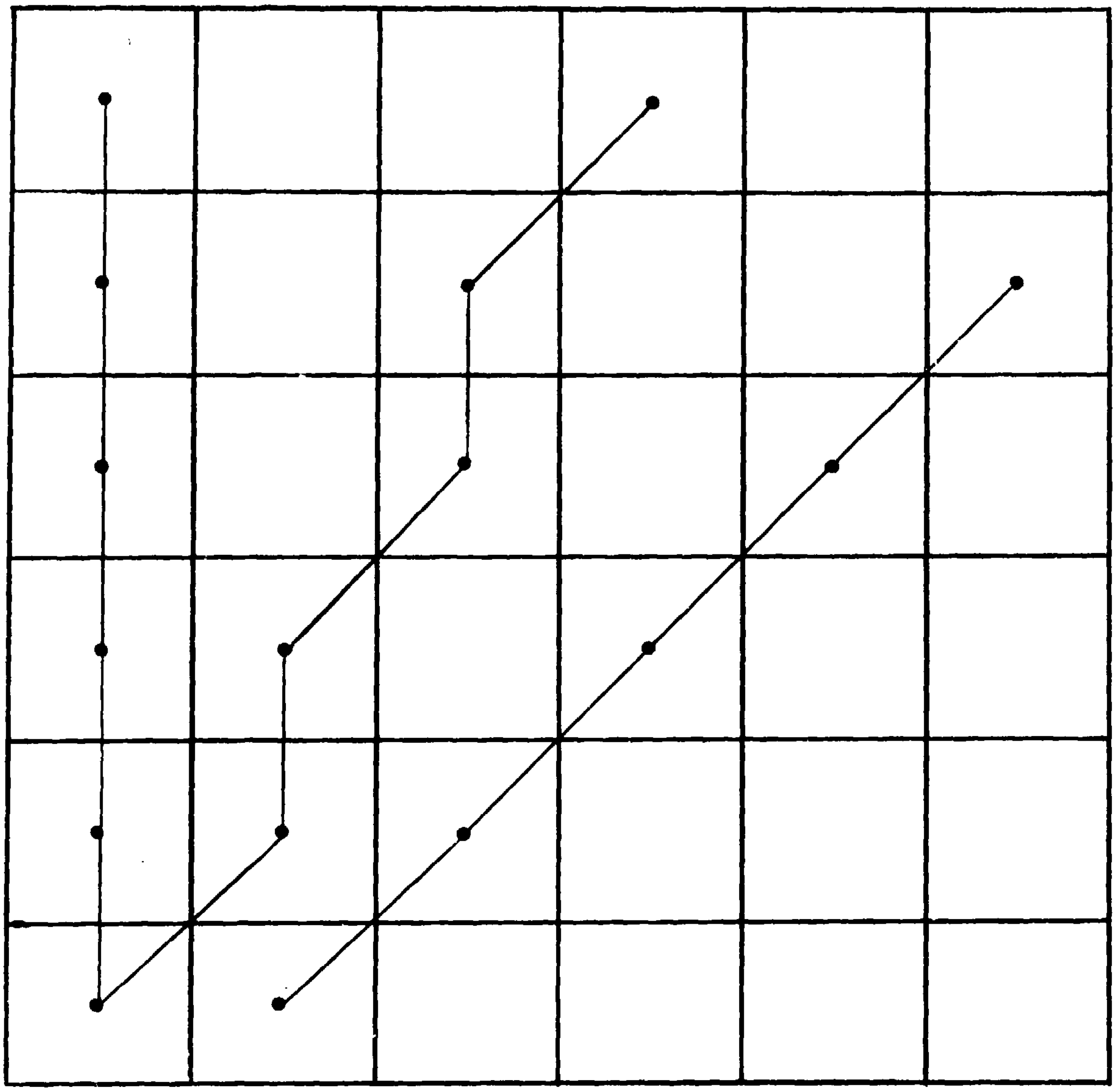


Figure 3-1. Terrain Profile Point Selection for CARMONETTE LOS Determination

placement and size of each triangle is at the discretion of the individual developing the data, the process is both highly flexible and highly subjective.

b. Intervisibility Calculations. An initial check is made on the vegetation height in the terrain triangle in which the observer is located. If this height is greater than the observer height, intervisibility does not exist. If the initial check does not find a vegetation blockage, the calculations proceed. Selection of points between which intervisibility calculations are to be made, a potential weak area in IUA, is discussed in the next subparagraph. Given a pair of points, IUA makes two intervisibility calculations from heights corresponding to an attack vehicle driver height and an attack vehicle commander height, with the attacker treated as potential observer. A single defensive target height is used for all calculations. These observer/target heights are added to the appropriate terrain elevations, as determined from the underlying triangle plane surfaces, to determine elevations of the LOS endpoints. The intervening terrain profile is defined at, and checks for interruption of the LOS are made at, every point where the LOS crosses a triangle leg. The profile elevation used at each check point is defined as the sum of the surface elevation at the crossing point (which is obtained by linear interpolation between the elevations of the vertices defining the leg) plus the average of the vegetation heights of the two triangles associated with the leg. Calculation complications enter when the crossing point is a triangle vertex, in which case the calculation uses the vertex height plus average vegetation height of the two triangles at that vertex that contain the LOS. In the rare case of an LOS coinciding with a triangle leg, the check would be made at each vertex. In this case, an arbitrary (but predictable) choice between the two triangles sharing the leg is made for the vegetation height calculation.

c. Preprocessor Control of Intervisibility Calculations.

(1) In IUA, selection of points between which intervisibility determinations are required is controlled by the general scheme of maneuver to be portrayed. Comprehension of this relationship requires the following definitions, for which an illustrative example is provided at figure 3-2.

(a) Routes. A route is a preselected trace describing the path of advance for a set of maneuver elements. Up to 12 routes may be used in a given scenario.

(b) Route descriptor. A route descriptor is a point used to specify changes in direction, soil type, terrain roughness, concealment, or tactics along a route. Route descriptors are manually developed by the model user. Up to 30 route descriptors may be input to define any one route.

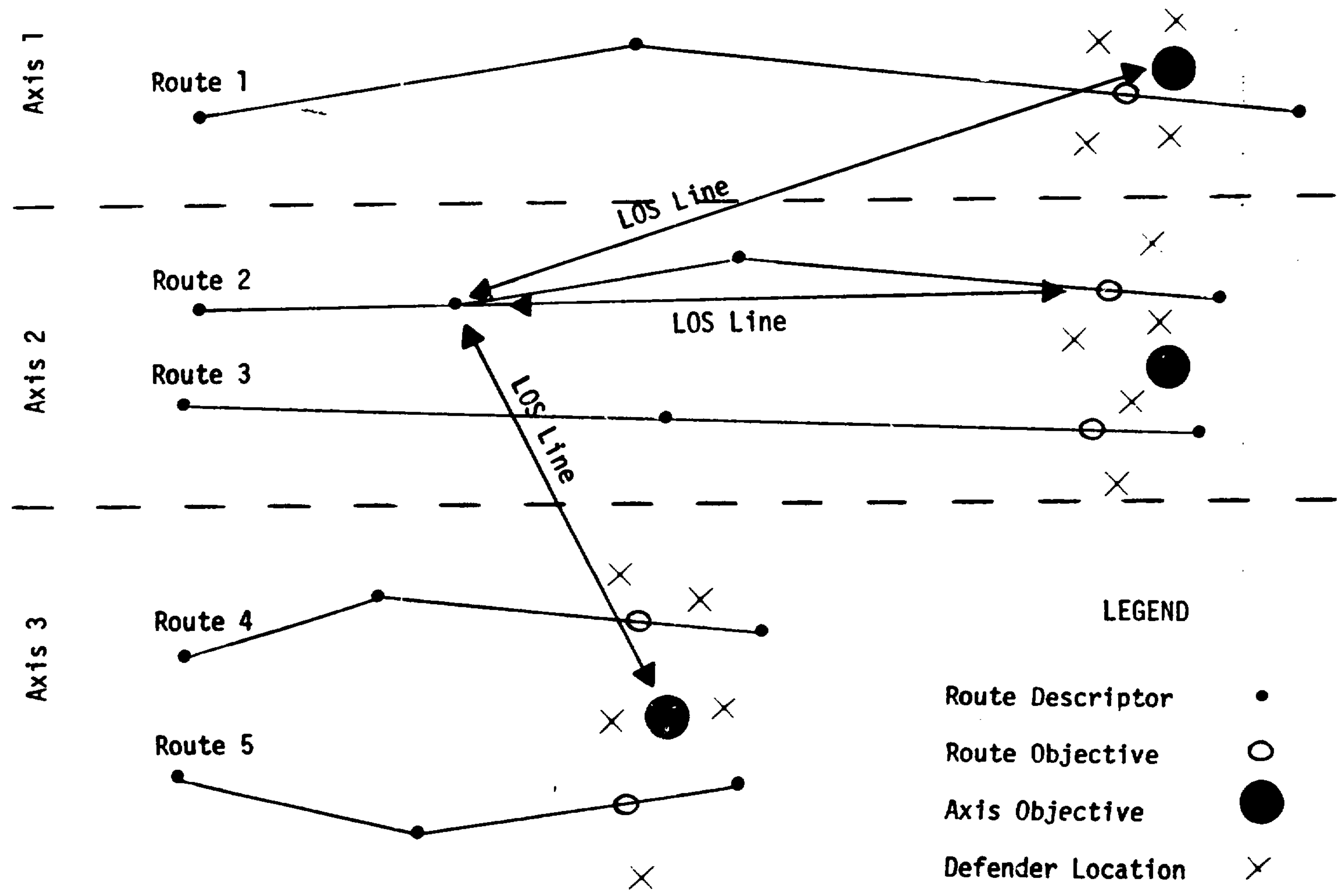


Figure 3-2. IUA Tactical Scenario

(c) Axis. An axis is a set of routes defined primarily to portray maneuver control measures. Up to three axes may be defined for a given scenario. The number of routes in any one axis is subject only to the constraint of 12 routes in a scenario.

(d) Objective Points. Objective points are points on the battlefield toward which the attacker routes and axes are directed. One objective point is defined for each route and for each axis.

(e) Sequence points. The IUA model adds points along each attacker route (between route descriptors). The added points are equidistant from each other, with the minimum number of such points that will attain a point to point distance less than 30 meters being used. These points, together with the original route descriptor points, are called sequence points.

(2) Intervisibility determinations are made from each route's sequence points. From each sequence point an LOS determination is made to the route objective point and, if multiple axes are used, to the axis objective points of those axes that do not include the route under consideration. Thus, with the limit of three axes, the determinations from a given route are made to at most three points on the battlefield. The same intervisibility determinations made for one objective point are then applied to all defender weapons associated with the axis containing that point, where the association of defensive weapons to attacker axis is accomplished by user input.

(3) Conditions established at one sequence point are applied along the route until the next sequence point. In the case of intervisibility, three conditions are defined for IUA: "fully exposed" if intervisibility exists from the lower (and by implication, the higher) observer height, "hull defilade" if intervisibility exists only from the higher observer height, "covered" if no intervisibility exists. These conditions are passed to the main model in the form of a table for each route indicating the sequence points at which a change of intervisibility occurs, s affected by the change, and new intervisibility conditions.

d. Additional Considerations.

(1) If the observer and target are in the same triangle, landform interruptions of the LOS cannot occur since the triangle is a plane surface. In this case, the only check made is on vegetation height within the triangle. If vegetation height exceeds observer height, intervisibility does not exist. Otherwise, intervisibility is assumed to exist.

(2) In addition to the basic intervisibility conditions, target acquisition is affected by a local concealment code, which is input for each defender weapon and for each route descriptor point. The values for a route descriptor point are applied to all attacker weapons on the route. Possible concealment levels are "fully exposed," "partially concealed" (essentially hull defilade), and "fully concealed." The effects of cover or concealment on the acquisition process are generally implemented by a group of go/no-go conditions, the rules for which are built into the model logic. The more important of these rules include:

(a) Acquisition of a firing target requires intervisibility but is not affected by "concealment" levels.

(b) Acquisition of a moving, non-firing target is possible beyond 750 meters only if the target is fully exposed (no cover and no concealment). At 250 to 750 meters, the moving non-firing target may also be detected under partial cover or partial concealment conditions. Additionally, the moving non-firing target may be detected in regions of full concealment at under 250 meters.

(c) Acquisition of a stationary, non-firing target requires full exposure at ranges beyond 250 meters. Inside 250 meters, detection is possible except in a fully covered position.

e. Significant Modifications. Significant modifications were made to the IUA model logic to produce the comparisons contained in this report.

(1) IUA logic was changed to allow the determination of intervisibility to individual defender locations rather than to apply intervisibility of route and axis objective points to all defender weapons in the area of the Site A experimental conditions. In representing Site A, the original model logic would have required the intervisibility characteristics of a single objective point to be applied to positions located both at the crest and at the foot of a ridgeline that dominates the valley in which approach routes were located. It was apparent that the positions on the ridgeline should have distinctively different intervisibility conditions from those at the foot of the ridge.

(2) IUA logic treating significant vegetation was changed to use the maximum vegetation height of the two terrain triangles associated with a triangle leg rather than average vegetation height. The original logic tended to negate the effects of isolated terrain triangles since it would, for such triangles, use half of the coded vegetation height (the average of the coded height and zero height for an adjoining non-vegetated triangle.)

3-5. DYNTACS INTERVISIBILITY.

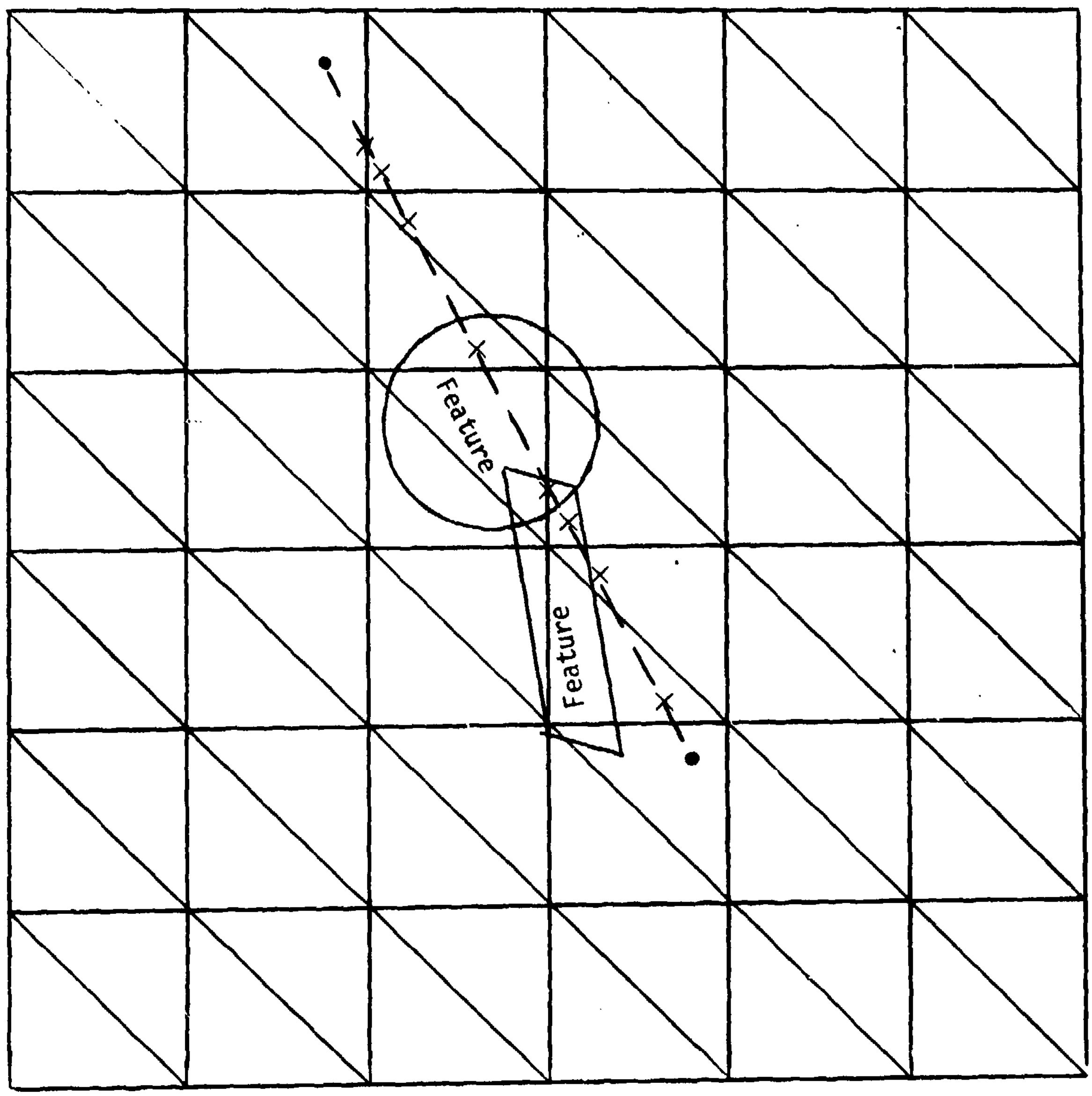
a. Terrain Representation. DYNTACS terrain representation contains features of both the CARMONETTE and IUA approaches, with the terrain surface and vegetation being treated in distinctly different manners. The major points, discussed below, are illustrated in figure 3-3.

(1) Terrain surface. Within DYNTACS, the terrain surface representation is based on a system of right triangles that is, in turn, based on a square grid system. Surface elevations are required for every grid line intersection; i.e., for the corners of each grid cell. Each grid cell is divided into two right triangles by the negative slope diagonal through the cell. The faces of the triangles thus defined are treated as contiguous plane surfaces, which, through linear interpolation, are used to define the basic elevation of any point on the battlefield. This planar representation of the terrain surface is termed the "macro-terrain" surface in DYNTACS vernacular.

(2) Terrain features and major vegetation. In addition to the square grid macro-terrain elevations, a system of circles and parallelograms is used in DYNTACS for the representation of other terrain characteristics. For a given characteristic, the set of associated circles and parellelograms, or features, serves the functional purpose of a map overlay, allowing the specification of regions of the battlefield that have a pertinent characteristic. Overlap of these geometric figures is permitted and is used as necessary to develop good approximations of the areas to be represented on each overlay. Terrain characteristics that can be specified with these features are, nominally: cover, concealment, forests, trafficability, and terrain roughness. Additionally, smoke and minefield features can be specified. Of these, the cover, concealment, and forest features are logically related to the issue of intervisibility representation. The forest features represent areas of significant vegetation, treated as LOS interruptions in the model. A single value of tree height (input specified) is used for all forest features on the battlefield.

(3) Other related features.

(a) Cover features. The planar landform representation achieved with the macro-terrain surface is a smoothed version of the surface that would be found in the field. In an attempt to portray local irregularities over this surface, DYNTACS applies a probabilistic adjustment to an element's macro-terrain elevation. The basic assumption made is that these micro-terrain elevation differences from the planar surface can be represented with a zero-mean normal distribution. The cover features are then used to define areas of the battlefield having essentially identical micro-terrain variations about the planar surface. Associated with each cover feature is the micro-terrain standard deviation to be used in drawing a random realization of the micro-terrain elevation



– – – = Line cf sight

× = Profile sample points (plane departure points)

Figure 3-3. DYNTACS Terrain Geometry and Profile Point Selection

for any point within the feature. Additionally, the power spectral density is provided for each cover feature. This is a measure of how rapidly the micro-terrain elevations can change within a very small region.

(b) Concealment features. As the cover features are intended to depict local details of the terrain surface, so are concealment features defined in DYNTACS to represent local details of the vegetation. Such local vegetation is defined in terms of "clumps," and a concealment feature is an area of homogeneous "clump" characteristics. Within a feature, the clumps are defined in terms of height and density. Several additional parameters are associated with each concealment feature, these parameters all coming into play in the target detection portions of the model.

b. Intervisibility Calculations. The basic determination of intervisibility in DYNTACS follows the standard pattern. Complications, discussed in the next paragraph, are introduced in the selection of micro-terrain elevations for a given element and in the interrelation of intervisibility and concealment as they impact upon target acquisition. Height of the endpoints of a line of sight to be checked for intervisibility are determined in terms of the macro-terrain elevation at the points in question, plus (or minus) a randomly drawn micro-terrain elevation, plus target or observer height, as appropriate. The intervening terrain profile is defined at those points where the LOS crosses a macro-terrain elevation triangle leg (or, equivalently, where the LOS crosses one of the square grid lines or negative slope grid diagonals). It should be noted that, since the triangles are treated as planar surfaces, the vertical slope of the surface can change only at these so-called "plane departure points." Thus, this set of points is the set that is both necessary and sufficient to define a terrain profile for intervisibility calculations, given that the planar representation of the surface is accepted. (The same statement is true for the points used to define a terrain profile within the IUA.) At each of these "plane departure points," the profile elevation is defined as the macro-terrain elevation of the point plus the forest height if that point lies within a forest feature. (Recall that a single value for forest height is applied over the entire battlefield.) The model actually calculates the percent of target height covered by the intervening terrain profile, and intervisibility is said to exist if less than 90 percent of the target height is covered.

c. Application of Micro-Terrain Elevations. An individual element's micro-terrain elevation; i.e., deviation from the planar terrain surface, is set every time the element's position is set within the model and remains fixed until the element moves. Three situations arise:

(1) Micro-terrain elevation of an element that is in its desired position at the outset of the game; e.g. a prepared defensive position or an overwatch position, may be set by input data. In this case, past practice has been to input a negative micro-terrain elevation in an effort to afford the element the cover it could attain in a hull defilade position.

(2) When a vehicle moves, but not into a firing position, micro-terrain elevation is set at the end of the movement event. The value used is a random draw from the zero-mean normal distribution with that standard deviation associated with the cover feature (if any) in which the movement event ends. (Typically, terrain data are loaded such that an appropriate "default" value is defined if the movement does not end within a cover feature.)

(3) The assumption is made that when a vehicle is moving into a firing position, a partially covered position will be sought. The desired degree of defilade is specified by an input value, and the probability of the vehicle finding the desired degree of cover is calculated based on the micro-terrain standard deviation and power spectral density associated with the feature in which the desired firing position is located. Success or failure in finding this degree of cover is based on a random draw. If, on the basis of this draw, the vehicle can find the desired degree of cover, then the appropriate micro-terrain elevation is used for the vehicle. If, on the basis of this draw, the desired micro-terrain elevation cannot be achieved, then a fraction of the desired micro-terrain elevation, based on a second random draw from a uniform (0 to 1) distribution, will be used.

d. Additional Considerations. In addition to the intervening landform and major vegetation, secondary vegetation in the vicinity of a potential target can have an effect on target acquisition. Secondary vegetation at the observer is not treated in the model. The effect depends primarily upon whether the potential target is moving or stationary and, for a stationary target, whether the target has fired recently.

(1) For a moving target, the "proportion of time that the target is not fully concealed" is applied to the algorithm used to calculate visual detection rates. This is a single input parameter, associated with each concealment feature, and applies to any moving element within the feature.

(2) For a stationary target, proportion of the target concealed by secondary vegetation is calculated. If the target is fully concealed, normal visual detection is not possible, but pinpoint detection may still take place. If partially concealed, the effective target size available for detections is reduced and used in the visual detection algorithm. This is accomplished by comparing the proportion of the target that is covered to the proportion that is concealed and letting the larger of these values apply to reduce the effective target size. The proportion of a target that is concealed is computed in a similar manner to intervisibility wherein possible obstruction of the LOS is considered only for one opaque clump of a given height located on the LOS trace some distance from the potential target. Clump height is one of the values associated with the concealment feature in which the target is located.

Clump density is also a concealment feature value; and this density is used, together with certain tactically related input values that apply to the total battlefield, to select randomly the distance of the clump from the potential target vehicle.

e. Significant Modifications. For the TETAM comparisons contained in this report, the DYNTACS treatment of all forest features as opaque interruptions to line of sight was changed to allow a probabilistic determination of whether a line of sight could pass through a forest feature. This modification treats a forest feature as being composed of a collection of homogeneous opaque cylinders, each of radius R and height H, randomly situated within the feature with some density D. Then, if that portion of a line of sight that is within the feature is of length L, the probability of the line of sight passing through the feature without being interrupted by any of the cylinders is simply e^{-2RLD} and the determination of intervisibility is based on comparing a random draw to this probability. The calculation is not made unless the height H is large enough to block intervisibility. This modification was incorporated to allow some consideration of the scattered trees throughout the experimental area when it became clear that the original model gave the option of either ignoring these trees, with resultant excessive intervisibility, or representing them by solid features, which resulted in unreasonably low intervisibility levels.

3-6. WES MODEL. At the time of publication of this report, current documentation of the WES model was not available. Based on available documentation of the approach used by Waterways Experimentation Station in a past intervisibility study (reference 7), the following differences of the WES approach from the other models are known.

a. The WES model uses terrain elevation and vegetation height data on a 25-meter square grid, a higher level of resolution than is normally used in the other models.

b. The elevation of any point is calculated in the WES model using the elevations of the four nearest grid data points. Quadratic interpolation is used; that is, the square of the distance from the point in question to each data point is used as a weighting factor. The resulting overall surface representation is thus a more smooth, continuous surface than attained with the other models.

c. The terrain profile along an LOS is defined at points every 25 meters from the observer. This is a generally closer spacing than used in the other models but is not a mathematically sufficient sample of the surface in the sense that local high and low points along the curved profile are not necessarily used.

3-7. SUMMARY. All four models are logically similar in their treatment of landform, major vegetation, and the impact of these on intervisibility. There is, however, considerable variance in the treatment of secondary vegetation or available concealment. The WES model makes no distinction between cover and concealment or between major and secondary vegetation. Considering the degree of artificiality with which the distinction is made in the other models, this may be the most sound approach philosophically. It does, however, force a homogeneity assumption and treatment of vegetation as being opaque within 25-meter cells. The original DYNTACS treatment of concealment is by far the most ambitious and sophisticated. Unfortunately, this treatment requires the user to input several tactically related variables for which there is no objective basis, particularly since these variables must apply to both forces over the total battlefield regardless of individual activity. The DYNTACS treatment of secondary vegetation is also one-sided in that a given element may be hidden by vegetation but that same vegetation can never hinder the element's detection activities. It should be noted that the revised vegetation treatment incorporated into DYNTACS is, in fact, a compromise between the two treatments contained in the original version. CARMONETTE treatment of secondary vegetation through the assignment of concealment indices to the grid squares leads to an even more difficult subjective data problem than that found in DYNTACS. Additionally, the treatment is again one-sided. The IUA approach is probably the weakest, in that for IUA the concealment is not even tied to the terrain but made to appear by fiat when a route is defined as concealed. Once more, treatment is one-sided. In addition to treating the concealment effects of secondary vegetation as being one-sided, each of the combat models (DYNTACS, CARMONETTE, and IUA) presents the data developer with a significant decision problem in deciding what should constitute significant, LOS-interrupting vegetation and what should be treated as secondary, concealment-providing vegetation. No guidelines for this decision are provided in any available model documentation.

CHAPTER 4

COMPARISON APPROACH

4-1. GENERAL. Comparisons of model representation of intervisibility with the data of Experiment 11.8 were made with the goals of determining the extent to which the models and field experiment are in agreement and explaining observed differences. The purpose of this chapter is to present the underlying orientation of the comparisons, areas of emphasis, variables used in the comparisons, and actual comparison methods used. Results of the comparisons are contained in the following chapters.

4-2. ORIENTATION. Ideally an intervisibility model would be able to produce correct line-of-sight determinations between any pair of points within the geographic region being represented. To assess the accuracy of representation of such a model, one could then select a number of sample points and compare model results on a point by point basis with ground truth; that is, with the actual existence of intervisibility between those points as determined by observation in the field. Further, given continued access to the experimentation site, it would be practical to determine those points at which the model was in disagreement with ground truth, explain the disagreement in terms of some observable difference between the model's representation and the physical reality in the field, and, where necessary, correct model deficiencies. The level of model precision implied by such a direct approach is neither present in the models nor claimed by the respective model developers. Similarly, while the nature or extent of errors in the Experiment 11.8 data is not known with any precision, it is clear that these data are not ground truth and have not been presented as such by the developing agency, CDEC. Additionally, the experimental site was not readily accessible to the study team making these comparisons, mitigating against specific error checking and model correction by return to the field. Thus, comparison of model results with those of Experiment 11.8 was required. Considering the intended use of the models, the comparisons were conducted with the intention of providing information in the following areas of interest.

a. In typical model applications, a limited number of terrain sites are actually simulated within the models. The user selects these sites as being, in some sense, representative of a larger geographic region of interest. The models should be able to portray accurately the general level of intervisibility on the selected terrain sites, since this is most likely one of the user's considerations in selecting representative sites.

b. Target acquisition and engagement are generally related to the battlefield geometry, in the sense that the relative positions of and ranges between opposing weapons can be determinants of which interactions are possible or will actually take place. Thus, the models should accurately reflect the levels of intervisibility between specific subareas of the battlefield, with particular emphasis on those areas likely to be occupied or traversed by opposing weapons.

c. Target acquisition and engagement are generally accepted as being processes that must take place over some span of time. Thus, the models should reflect the changes to or, as appropriate, stability of intervisibility conditions over time spans typically associated with target acquisition and engagements. In the case of moving targets and/or weapons, this translates into a requirement to reflect accurately patterns of continuous or intermittent intervisibility along a movement trace.

d. The target acquisition and engagement processes are generally accepted as being related to the physical dimensions of the potential target. Thus, a model should be able to reflect differences in intervisibility between targets of various dimensions when these targets are portrayed as being located at the same point on the battlefield.

4-3. COMPARISON VARIABLES. In comparing model results to the results of Experiment 11.8 analysis was constrained to those variables contained in or directly derived from the Experiment 11.8 data. Although the errors associated with these data are assumed to be modest, they are unmeasured and could be greater than assumed. In defining comparison variables attempts were made to remain as close to the fundamental data as practicable to minimize the danger of the unknown errors being propagated and perhaps amplified within derived variables. Thus, in review of the three basic measures discussed below, P_{LOS} is considered preferable because of its relative lack of sensitivity to potential error.

a. <u>Fundamental Data</u>.

(1) The items actually available within the Experiment 11.8 data base include: UTM coordinates of target panels; UTM coordinates of approximately 70 percent of the approach route viewing positions (stakes); physical dimensions of the target panels; the two heights above ground level from which all observations were to be made; the lowest portion (color band) of each target panel as observed from each approach route viewing position; perceived nature of each line-of-sight interruption as being caused by landform, vegetation, cultural (man-made) features, or as being unknown. Of these the experimental <u>output</u> is limited to the line of sight and interruption determinations. The remaining data, while <u>input</u> to the experiment (and to the models), are also subject to some measurement error as was discussed in chapter 2.

(2) The variable indicating the lowest portion of a target panel observed logically may be treated as three YES-NO variables, each indicating presence or absence of intervisibility to one of the panel's color bands; that is, if the low band is reported visible, intervisibility is assumed to all three bands; if the middle band is reported visible, intervisibility is assumed to the top and middle bands; if the top band is reported visible, intervisibility is assumed for the top band only.

(3) As discussed above, the most direct comparison possible would have been to compare the basic YES-NO variable from the field to a similar determination made by the models for each target panel/viewing position/height combination. The IUA and CARMONETTE models, however, are constrained in the number of viewing positions that can be used, making a stake by stake comparison for these models impracticable. If this constraint were removed, the inherent errors involved in location measurements made in Experiment 11.8 would combine in an unknown manner with positioning errors relative to the simulated environment inherent in each of the models. These combined errors make it doubtful that the models, even if they were perfect representations in all other aspects, could reproduce the results associated with each discrete location involved in the conduct of Experiment 11.8. Thus, the fundamental data were not used in comparisons.

b. Probability of Line of Sight (P_{LOS}). For a given set of determinations of the existence of intervisibility, the probability of line of sight, P_{LOS}, is defined as the proportion of successful determinations; that is, P_{LOS} is the number of determinations for which intervisibility exists divided by the total number of determinations. This variable is used extensively in the comparisons reported in the ensuing chapters.

(1) Strengths of P_{LOS}. P_{LOS} is an attractive variable for comparisons of the type made in this study for two major reasons.

(a) If P_{LOS} is based on a large number of determinations the variable is a reasonably stable indicator of overall intervisibility in the sense that a modest number of erroneous determinations will not have a pronounced effect on the resultant P_{LOS}. This is important because an assumed modest, but actually unmeasured, amount of error is generally accepted as being present in the basis of comparison, the Experiment 11.8 data.

(b) If two sets of determinations of intervisibility have been made for the same conditions, the exact number of determinations contained in each set is not critical to calculation of P_{LOS}. Thus, in those cases where it is impracticable to attempt the exact number of determinations present in the Experiment 11.8 data base, a comparable P_{LOS} can still be calculated.

(2) Limitations of P_{LOS}.

(a) P_{LOS} reflects the general level of intervisibility for the conditions, taken as a whole, under which the set of determinations used to calculate the variable were made. For a large number of determinations these conditions may be impossible to define with any precision. For example, the 36 ATM positions on Site A were located such that about half of the positions were at or near the crest of a significant ridgeline, while the remaining positions were generally at the base or to the front of the ridgeline. These two sets of positions should have distinctively different intervisibility characteristics. When P_{LOS} is calculated

over all 36 positions, the result reflects the intervisibility level taken as a whole. It is, in fact, too low to represent any one of the positions on the ridge and too high to represent any one of the positions to the front of the ridge. Thus, the precise meaning of intervisibility level "from the defensive position" becomes elusive.

(b) The study team is not aware of any generally applicable statistical technique for comparison of P_{LOS}. The major problems are that for any test involving the binomial distribution the probability of success must be assumed constant from trial to trial, and that for these and any other tests reviewed the determinations must be independent events. Consideration of the phenomenon measured and the procedures followed in Experiment 11.8 make it clear that neither of these conditions is met.

c. Line-of-Sight Segments. A line-of-sight segment is a portion of one of the approach routes upon which intervisibility to a given target panel (ATM position) is assumed to exist without interruption. A line-of-sight segment of N stakes is said to exist for each series of N consecutive viewing points from which intervisibility to a given target is reported. The length of a line-of-sight segment is the cumulative point-to-point distance between points composing the segment plus half the distance from the viewing point at each end of the segment to the previous or following point, as appropriate, at which intervisibility was reported not to exist. Thus, if the distance between consecutive viewing points was precisely 25 meters, a line-of-sight segment of N stakes would be exactly 25 X N meters long. The line-of-sight segment and associated variables are used in the comparisons.

(1) Strengths of the line-of-sight segment. The existence of intervisibility between opposing weapons systems generally is accepted as being a critical determinant of whether a potential target will be acquired and engaged. Thus, if a logical progression of events on the battlefield is to be simulated, it is apparent that the sequence of intervisible and non-intervisible periods for any pair of opposing weapons should be represented faithfully. The representation of intervisibility by means of line-of-sight segments reflects this transition over time and space between intervisible and non-intervisible conditions. The line-of-sight segment, therefore, is a desirable comparison variable because of its high degree of relevance.

(2) Limitations of the line-of-sight segment. Use of the line-of-sight segment as a comparison variable must be tempered by the fact that this measure appears to be highly sensitive both to variations in the measurement technique and to errors in measurement. A study of the sensitivity of mean segment length, number of segments, and P_{LOS} to the interval at which measurements are made has been conducted by the US Army Human Engineering Laboratory (reference 8). This study indicates that the measures related to line-of-sight segments can be highly sensitive to the measurement interval. This points up the probable error in the

assumption that intervisibility or a lack of intervisibility continues uninterrupted between discrete viewing points. The degree of sensitivity will, of course, depend on the distance between viewing points used in the determinations as well as the nature of the terrain under study. An investigation of the sensitivity of these same measures (mean segment length, number of segments, and P_{LOS}) to possible errors within the fundamental intervisibility data was conducted as part of the TETAM intervisibility comparison study and is reported in appendix B to this report. Once more, the measures related to intervisibility segments were found to be highly sensitive, in this case to relatively low error rates in the fundamental data.

4-4. COMPARISON METHODS. Two related comparison processes and their results are reported in the following chapters.

a. Basic Comparisons. The basic comparisons, reported in chapter 5, document the extent to which model results agree with those of Experiment 11.8. These basic comparisons focus upon the questions of how well the models may be expected to portray general levels of intervisibility and how well they reflect the patterns of intervisibility between discrete weapons. The comparisons in chapter 5 are limited to one of the six observer/target panel height combinations since, although the degree of sensitivity to observer/target heights is at issue, the results of the basic comparisons reported in chapter 5 are essentially the same for any height combination.

(1) General intervisibility levels.

(a) General intervisibility levels are compared in terms of P_{LOS} resulting from the field experiment and from similar determinations obtained from each of the models. The approach followed in these comparisons is to select some subset of the determinations made in Experiment 11.8 and that portion of the model results that represent the same determinations. P_{LOS} is then calculated for each of these data sets. Thus, for example, the overall level of intervisibility between a selected target panel and one of the approach paths could be developed by selecting all field experiment and model determinations for that target/path combination and calculating the appropriate P_{LOS}.

(b) The number of data subsets that conceivably could be selected for comparison is too large for consideration. An attempt was made to select those subsets that indicate the extent and general nature of model/field experiment agreement.

(c) An objective decision criterion for determining whether the P_{LOS} resulting from the models is in agreement with P_{LOS} from Experiment 11.8 data is not known. The interpretation of significance of difference in P_{LOS} is based on the judgments of the author. The individual reviewer should apply his interpretations to such differences; and every attempt has been made to provide sufficient information to allow the reviewer to reach his own conclusions.

(2) Intervisibility patterns. The existence or nonexistence of intervisibility between a single pair of discrete points on the battlefield is of limited value in establishing opportunities for target detection or engagement when the potential firer and/or target are in motion. In this case, intervisibility should continue essentially uninterrupted over some portion of a movement trace to allow detection or engagement. The investigation of such intervisibility patterns using the available Experiment 11.8 data requires assumptions such as those used in defining line-of-sight segments, and the weakness of those assumptions must be held in mind.

(a) The primary comparison of intervisibility segments is oriented on simple descriptive statistics of the segment populations generated from the field data and model results. The question is whether the models produce approximately the same number of segments of approximately the same length as are contained in the field data.

(b) A second comparison is based on an attempt to relate segment lengths to engagement opportunities. An engagement opportunity is said to exist if an intervisibility segment is sufficiently long to allow an ATM weapon crew to detect, fire on, and guide the missile to a target moving along the segment. The essential parameters involved are the crew detection and firing times, the missile flight time, and the distance the target will move within these combined times. The crew response time will vary from crew to crew and from situation to situation. For comparison purposes, representative response times of 10, 25, and 50 seconds are used. Missile flight time depends on missile speed and range to the target. For the comparisons a missile speed of 200 meters per second is used, and range bands of 0-1000, 1000-1500, 1500-2000, 2000-2500, 2500-3000, 3000-3500, 3500-4000, and over 4000 meters are used. The distance a target moves is calculated based on a movement rate of 3.5 meters per second (12.6 kph) for these comparisons.

b. Side Analysis. Several side analyses of potential interest are reported in chapter 6. These include an investigation of the DYNTACS intervisibility model's sensitivity to different random number sequences (DYNTACS was the only model studied for which intervisibility calculations are not deterministic), an investigation of the impact of varying target/observer heights on the field and model results, a re-analysis of the engagement opportunities with an increased target speed of 5 meters per second (18 kph), and a subjective look at the extent to which vegetation patterns noted at the HLMR sites might be expected in a European situation.

CHAPTER 5

BASIC COMPARISON RESULTS

5-1. GENERAL. Results of the basic comparisons of model and experimentally determined intervisibility are contained in this chapter.

a. These comparisons are limited to results for the high observer/high ATM panel height combination. The observer's eye level is assumed to be at the highest point on a threat ATGM vehicle, as is the ATM panel color band representing the height of the M551. Variations of target and observer heights are treated by a sensitivity analysis in the next chapter.

b. Where significant model modifications have been made, the comparisons generally reported in this chapter are based on results obtained with the modified models. Results obtained with the original models are reported for selected comparisons, where the inclusion of this information is considered illustrative of the effects of the modification. The indicated modifications were introduced in chapter 3.

(1) IUA modifications determine intervisibility based on individual defender weapon positions rather than objective points; and they consider the full vegetation height of individual triangles rather than the average vegetation height in adjoining triangles.

(2) DYNTACS modifications allow a probabilistic determination of the ability to see through forest features.

c. Results of the basic comparisons in most cases are arranged so that the less demanding comparisons are discussed early and progressively more demanding comparisons follow. This order of presentation is based on the premise that if a model is in clear disagreement with the field results on the earlier comparisons, then the more demanding comparisons belabor the obvious and will be of little interest to readers.

5-2. OVERALL INTERVISIBILITY LEVEL COMPARISONS. Table 5-1 shows the overall probability of line of sight reported in the field experiment and generated by each model for the three experimental conditions. An absolute difference of plus or minus 5 percentage points is considered to be in general agreement with the field results; differences of up to 10 percentage points indicate a questionable level of agreement; and differences of greater than 10 percentage points are clearly indicative of a lack of agreement with the field results. On the basis of these criteria, the revised DYNTACS and IUA representations are in general agreement with field results for each of the three conditions, and the WES model in agreement for the Site A conditions. CARMONETTE attains a questionable level of agreement on Site A, and both the CARMONETTE and WES results clearly diverge from field results on Site B.

Table 5-1. Overall Intervisibility Levels (P_{LOS})

Data Source	Site A Rapid Approach	Site A C&C Approach	Site B
Experiment 11.8	.29	.25	.18
CARMONETTE	.37	.35	.45
DYNTACS (revised)	.31	.29	.19
IUA (revised)	.27	.24	.18
WES	.25	.24	.06
DYNTACS (original)	.49	.48	.61
IUA (original)	.42	.34	.19

5-3. INTERVISIBILITY LEVELS BETWEEN DEFENSIVE AREA AND APPROACH ROUTE BANDS.

a. Basis of Comparison.

(1) To obtain an indication of intervisibility levels between the general area occupied by defensive weapons and different portions of the battlefield, the areas containing approach routes have been segmented into individual bands, 500 meters in width, generally normal to the axis of advance. The reader is cautioned that the intervisibility values reported for these bands do not reflect intervisibility as a function of discrete observer to target range. Rather, they reflect levels of intervisibility between general areas of the terrain used in the study. Although the overall likelihood of intervisibility does tend to decrease as the range between the areas increases, the nature of this change may be as much a unique characteristic of the actual terrain used as it is a general range-dependent phenomenon.

(2) The same acceptance criteria used in overall PLOS comparisons are suggested for the comparison of intervisibility levels of approach route bands, that is, an absolute difference of up to 5 percentage points indicates that the model is in agreement with field results; an absolute difference of more than 5 but no more than 10 percentage points indicates a questionable level of agreement; and an absolute difference of more than 10 percentage points indicates a clear disagreement between model and field results.

b. Site A Comparisons.

(1) P_{LOS} results by approach route band for the Site A-Rapid Approach condition are shown in table 5-2. None of the models is in close agreement with the field data over all approach route bands. DYNTACS and IUA results are in agreement with field results in five of the eight bands and, on the whole, follow the field results more closely than do the CARMONETTE or WES results. These results are generally repeated for the Site A Covered and Concealed Approach condition, for which P_{LOS} results by approach route bands are shown in table 5-3.

(2) In addition to the separate range band comparisons, a general structure of the intervisibility process is apparent in the Experiment 11.8 data for Site A. Under the rapid approach conditions, a relatively high intervisibility level is found over bands A, B, C, and D. This is followed by an intermediate level in band E and a low level of intervisibility in bands F, G, and H. The same structure is apparent for both the CARMONETTE and DYNTACS results. This structure, however, is not as apparent in the results from the IUA or WES models. Neither IUA nor WES results show the intermediate level of intervisibility at band E; and, in fact, what might be considered an intermediate

Table 5-2. P_{LOS} within Approach Route Bands - Site A Rapid Approach.

Data Source	Band/Distance from Defender Area (meters)							
	A/0-500	B/500-1000	C/1000-1500	D/1500-2000	E/2000-2500	F/2500-3000	G/3000-3500	H/over 3500
Experiment 11.8	.40	.56	.42	.50	.21	.02	.07	.08
CARMONETTE	.49	.54	.47	.61	.28	.14	.18	.19
DYNTACS (revised)	.40	.51	.42	.48	.30	.09	.10	.14
IUA (revised)	.51	.54	.34	.47	.13	.01	.11	.08
WES model	.48	.57	.27	.37	.10	.00	.09	.14
DYNTACS (original)	.50	.67	.52	.56	.45	.39	.45	.34
IUA (original)	.56	.55	.39	.61	.43	.17	.42	.27

Table 5-3. P_{LOS} within Approach Route Bands - Site A C&C Approach

Data Source	Band/Distance from Defender Area (meters)							
	A/0-500	B/500-1000	C/1000-1500	D/1500-2000	E/2000-2500	F/2500-3000	G/3000-3500	H/over 3500
Experiment 11.8	.47	.48	.23	.38	.18	.03	.07	.07
CARMONETTE	.53	.53	.34	.45	.23	.15	.19	.24
DYNTACS (revised)	.47	.49	.25	.42	.30	.09	.10	.09
IUA (revised)	.59	.48	.16	.36	.12	.01	.12	.08
WES model	.60	.55	.12	.27	.09	.00	.10	.11
DYNTACS (original)	.56	.72	.30	.49	.49	.39	.43	.29
IUA (original)	.55	.36	.13	.55	.36	.20	.42	.24

intervisibility appears in band C for the IUA results and in bands C and D for the WES results. A similar structure for the Site A-Covered and Concealed Approach condition is found, with the experimental results indicating relatively high intervisibility levels in bands A, B, and D; intermediate levels in bands C and E; and relatively low levels in bands F, G, and H. In this case, the observed structure was reproduced most faithfully by the DYNTACS results. CARMONETTE results differ in that there is little distinction among the intermediate and low level bands, with a pronounced overstatement of intervisibility in bands F, G, and H. The IUA and WES results also fail to discriminate between the intermediate and low level bands, with an understatement of the relative intervisibility within the intermediate level bands C and E.

c. Site B Comparisons. P_{LOS} results by approach route bands for Site B are shown in Table 5-4. CARMONETTE and WES model results are clearly different from those obtained in the field experiment, while IUA and DYNTACS model results are in general agreement with field results. It is notable that IUA model results in the first band are consistently 10 to 12 percentage points higher than those of the field experiment for each of the three experimental conditions.

5-4. INTERVISIBILITY LEVELS FOR DISCRETE TARGET LOCATIONS.

a. General. The previously reported comparisons of intervisibility levels, which are computed over all target locations, have a limitation in that serious anomalies could be masked if offsetting errors are present. For example, if one target were to be masked from all viewing points (P_{LOS}=0) and another target were visible from all viewing points (P_{LOS}=1), the overall P_{LOS} for these targets would be .50. A model conceivably could be incorrect on both targets, giving P_{LOS}=1 to the totally masked target and P_{LOS}=0 to the totally visible target, and still achieve an overall P_{LOS}=.50. The presentation of P_{LOS}=.50 for both cases will lead to the incorrect conclusion of total agreement. To preclude such results, P_{LOS} for each discrete target location under each of the three trial conditions is compared below. These data lend themselves to two comparisons. First, the field experiment results allow the identification of certain target locations that have relatively high or relatively low levels of intervisibility over the approach routes. The model results should allow a consistent identification of positions with relatively "good" and "poor" intervisibility. Secondly, the difference in P_{LOS} between experimental results for each target and those results attained with the models indicates whether the models have a consistent error bias over all targets or whether the models do well with some target locations but break down on others.

Table 5-4. P_{LOS} within Approach Route Bands - Site B

Data Source	Band/Distance from Defender Area (meters)							
	A/0-500	B/500-1000	C/1000-1500	D/1500-2000	E/2000-2500	F/2500-3000	G/3000-3500	H/over 3500
Experiment 11.8	.44	.28	.09	.07	.04	---	---	---
CARMONETTE	.77	.64	.36	.31	.36	.17	.01	---
DYNTACS (revised)	.45	.33	.09	.07	.05	.01	---	---
IUA (revised)	.54	.27	.05	.03	.00	---	---	---
WES model	.22	.03	.01	.02	.00	---	---	---
DYNTACS* (original)	.90	.85	.53	.49	.58	.25	---	---
IUA (original)	.39	.32	.02	.13	.12	.04	---	---

b. Site A Results. Overall P_{LOS} results for each target position of Site A are contained in table 5-5 for the rapid approach routes and in table 5-6 for the covered and concealed routes. Target positions are listed in descending order of P_{LOS} as determined by the Experiment 11.8 data. In each case, the 17 positions with the highest P_{LOS} are all located high on the forward slope or at the crest of the ridgeline that dominates the approach routes, and the remaining positions are located at the foot or to the front of the ridgelines.

(1) Each model discriminates moderately well among target positions for which relatively high or low intervisibility levels were reported in the field experiement results. The approach used in this comparison is to select the 12 positions with the highest intervisibility levels and the 12 positions with the lowest intervisibility levels based on model results and to compare these positions with the same selection made using the experimental results. Selections using the DYNTACS results are, on the whole, slightly better, as discussed below.

(a) In selecting the 12 best positions for the rapid approach routes, two errors would be made using the DYNTACS results and three errors would be made using the data from any of the other three models. The error would be modest with the DYNTACS results in that positions 23 and 4 (with experimentally determined P_{LOS} of .37 and .35) would replace positions 15 and 28 (with experimentally determined P_{LOS} of .42 and .39), respectively. A relatively severe error would be made using IUA or WES results to select best positions, both of which would fail to identify position 2, which had the highest P_{LOS} level in the experimental data.

(b) In selecting the 12 poorest positions using model data for the rapid approach routes, two errors would be made with the DYNTACS or WES results, three errors with the IUA results, and four errors with the CARMONETTE results.

(c) In selecting the 12 positions with greatest overall intervisibility levels using model results for the covered and concealed approach routes, two errors would be made using DYNTACS results and three errors using results of any of the other models.

(d) Four errors would be made in identifying the 12 positions with least overall intervisibility on the covered and concealed routes by use of the DYNTACS, CARMONETTE, or WES results. Five errors would be made with the IUA model results.

(2) The differences between overall P_{LOS} as recorded in Experiment 11.8 for the Site A target positions and as determined from model results are contained in table 5-7 for the rapid approach routes.

Table 5-5. P_{LOS} by ATM Position - Site A, Rapid Approach Routes.

Panel Number	Exp 11.8	CARMONETTE	DYNTACS	IUA	WES
2	.50	.51	.53	.38	.37
21	.49	.66	.55	.48	.38
6	.47	.71	.56	.47	.36
10	.47	.62	.56	.46	.41
17	.47	.41	.54	.47	.45
1	.45	0.00	.52	.23	.32
3	.44	.57	.54	.36	.36
13	.44	.68	.55	.47	.38
22	.44	.66	.56	.47	.42
16	.43	.66	.53	.47	.47
15	.42	.69	.35	.48	.45
28	.39	.45	.29	.50	.38
29	.39	.49	.32	.39	.30
14	.38	.69	.32	.48	.39
23	.37	.66	.43	.48	.43
4	.35	.50	.44	.02	.26
27	.32	.45	.26	.29	.38
11	.28	.31	.08	.27	.29
9	.26	.30	.31	.15	.18
5	.25	.17	.18	.17	.11
8	.25	.30	.32	.19	.18
35	.23	.04	.12	.23	.15
20	.22	.25	.27	.02	.20
7	.21	.29	.33	.19	.19
25	.21	.09	.12	.14	.10
30	.19	.01	.15	.36	.15
32	.19	.32	.05	.18	.07
18	.18	.25	.28	.14	.21
26	.16	.35	.15	.09	.16
19	.15	.21	.18	.14	.13
12	.13	.26	.24	.14	.15
24	.10	.26	.14	0.00	.14
31	.09	.10	.08	.08	.04
36	.09	.35	.15	.37	.08
33	.04	.06	.14	.03	0.00
34	.03	0.00	.07	.01	0.00

Table 5-6. P_{LOS} by ATM position - Site A, Covered and Concealed Approach

Panel Number	Exp 11.8	CARMO-NETTE	DYNTACS	IUA	WES
21	.45	.59	.53	.43	.36
17	.43	.35	.53	.43	.41
10	.42	.63	.55	.40	.40
2	.41	.41	.51	.31	.35
6	.40	.71	.54	.40	.33
13	.40	.73	.47	.42	.37
22	.40	.69	.53	.43	.39
1	.39	.01	.47	.14	.30
29	.37	.48	.31	.35	.29
16	.36	.65	.56	.44	.42
15	.35	.73	.24	.44	.41
23	.34	.69	.37	.44	.40
28	.34	.43	.28	.45	.35
3	.31	.51	.52	.24	.34
14	.31	.73	.28	.43	.38
4	.28	.43	.35	.03	.23
27	.26	.43	.17	.21	.34
25	.21	.14	.12	.17	.13
35	.21	.04	.10	.25	.17
9	.20	.22	.26	.10	.15
5	.19	.09	.16	.12	.10
8	.19	.22	.25	.14	.15
20	.19	.17	.22	.04	.14
26	.19	.35	.15	.10	.17
30	.17	.02	.15	.32	.18
32	.17	.34	.06	.17	.10
11	.15	.17	.07	.23	.28
7	.14	.22	.25	.14	.17
24	.14	.25	.17	0.00	.15
18	.13	.17	.25	.11	.18
19	.13	.16	.13	.11	.11
31	.12	.14	.13	.13	.10
12	.08	.14	.21	.09	.10
36	.05	.32	.17	.36	.10
33	.02	.03	.12	.01	0.00
34	.01	0.00	.07	.02	0.00

Table 5-7. P_{LOS} Differences - Site A, Rapid Approach Routes.

Panel Number	P_{LOS} In Exp 11.8	Model Differences			
		CARMONETTE	DYNTACS	IUA	WES
2	.50	.01	.05	-.12	-.13
21	.49	.17	.06	-.01	-.11
6	.47	.24	.09	0.00	-.11
10	.47	.15	.09	-.01	-.06
17	.47	-.06	.07	0.00	-.02
1	.45	-.45	.07	-.22	-.13
3	.44	.13	.10	-.08	-.08
13	.44	.24	.11	.03	-.06
22	.44	.22	.12	.03	-.02
16	.43	.23	.10	.04	.04
15	.42	.27	-.07	.06	.03
28	.39	.06	-.10	.11	-.01
21	.39	.10	-.07	0.00	-.09
14	.38	.31	-.06	.10	.01
23	.37	.29	.06	.11	.06
4	.35	.15	.09	-.33	-.09
27	.32	.13	-.06	-.03	.06
11	.28	.03	-.20	-.01	.01
9	.26	.04	.05	-.11	-.08
5	.25	-.08	-.07	-.08	-.14
8	.25	.05	.07	-.06	-.07
35	.23	-.19	-.11	0.00	-.08
20	.22	.03	.05	-.20	-.02
7	.21	.08	.12	-.02	-.02
25	.21	-.12	-.09	-.07	-.11
30	.19	-.18	-.04	.17	-.04
32	.19	.13	-.14	-.01	-.12
18	.18	.07	.10	-.04	.03
26	.16	.19	-.01	-.07	0.00
19	.15	.06	.03	-.01	-.02
12	.13	.13	.11	.01	.02
24	.10	.16	.04	-.10	.04
31	.09	.01	-.01	-.01	-.05
36	.09	.26	.06	.28	-.01
33	.04	.02	.10	-.01	-.04
34	.03	-.03	.04	-.02	-.03

These results are considered to be in agreement with experimental results if the absolute difference is 5 percentage points or less and in serious disagreement if the absolute difference is greater than 10 percentage points.

(a) For the rapid approach routes (table 5-7) the WES and IUA comparisons are similar in that both models agree with the field experiment on 19 of the 36 positions and are in serious disagreement on 7 and 9 positions, respectively. The similarity ends here; and there are seven cases (positions 6, 20, 21, 28, 30 32, and 36) where one of the models agrees with experimental results while the other model is in serious disagreement. Where serious disagreement does appear, it is more pronounced for the IUA results. In four cases, IUA results differ from those of the field by 20 percentage points or more, while the largest disagreement found with the WES data is 14 percentage points. DYNTACS results are in serious disagreement with field results on seven positions and are within 5 percentage points of field results on only nine positions. CARMONETTE results are in serious disagreement with the field data on 21 of the 36 positions.

(b) For the covered and concealed approach routes (table 5-8), WES results are in much closer agreement with field results than are the other models. In this case, WES results seriously disagree with field results on only one position and are in agreement on 23 of the 36 positions. IUA results are essentially the same as they were for the rapid approach routes, the model tends to be in close agreement or serious disagreement with field results for the same positions under either condition. DYNTACS comparisons deteriorate somewhat, with serious disagreement on 12 positions. The level of agreement remains poor for CARMONETTE results, with serious disagreement for 20 positions and with absolute differences of over 20 percentage points on 11 of these positions.

(c) The results of comparisons of intervisibility levels between the defensive area and approach route bands and intervisibility levels for discrete ATM positions for Site A could be considered contradictory in that the WES model compares well with field results for the discrete positions but does not appear comparable for the approach route bands. Similarly, DYNTACS model results for Site A are compatible with the field results for approach route bands but do not agree well for discrete ATM positions. Review of the more detailed data to consider the intervisibility levels to approach route bands for individual ATM positions sheds some light on the apparent contradictions.

1 The WES results for Site A, Covered and Concealed Approach in table 5-3 contain a distinctive pattern, with the model P_{LOS} too high on the first two bands and too low on the next three when compared with field results. This same pattern, high on the first

Table 5-8. P_{LOS} Differences - Site A, Covered and Concealed Approach.

Panel Number	P_{LOS} In Exp 11.8	Model Differences			
		CARMONETTE	DYNTACS	IUA	WES
21	.45	.24	.08	-.02	-.09
17	.43	-.08	.10	0.00	-.02
10	.42	.21	.13	-.02	-.02
2	.41	0.00	.10	-.10	-.06
6	.40	.31	.14	0.00	-.07
13	.40	.33	.07	.02	-.03
22	.40	.29	.13	.03	-.01
1	.39	-.38	.08	-.25	-.09
29	.37	.11	-.06	-.02	-.08
16	.36	.29	.20	.08	.06
15	.35	.38	-.11	.09	.06
23	.34	.35	.03	.10	.06
28	.34	.09	-.06	.11	.01
3	.31	.20	.21	-.07	.03
14	.31	.42	-.03	.12	.07
4	.28	.15	.07	-.25	-.05
27	.26	.17	-.09	-.05	.08
25	.21	-.07	-.09	-.04	-.08
35	.21	-.17	-.11	.04	-.04
9	.20	.02	.06	-.10	-.05
5	.19	-.10	-.03	-.07	-.09
8	.19	.03	.06	-.05	-.04
20	.19	-.02	.03	-.15	-.05
26	.19	.16	-.04	-.09	-.02
30	.17	-.15	-.02	.15	.01
32	.17	.17	-.11	0.00	-.07
11	.15	.02	-.08	.08	.13
7	.14	.08	.11	0.00	.03
24	.14	.11	.03	-.14	.01
18	.13	.04	.12	-.02	.05
19	.13	.03	0.00	-.02	-.02
31	.12	.02	.01	.01	-.02
12	.08	.06	.13	.01	.02
36	.05	.27	.12	.31	.05
33	.02	.01	.10	-.01	-.02
34	.01	-.01	.06	.01	-.01

two bands and low on the next three, is contained in the detailed data for 25 of the 36 ATM positions. It appears that, although the model is producing appropriate overall intervisibility levels for the discrete positions, the intervisibility occurs to the wrong places on the battlefield. One potential explanation is that the model is portraying the area containing the ATM positions fairly well but is not depicting the rest of the battlefield properly.

2 DYNTACS results for Site A, Covered and Concealed Approach are close to those of the field for approach route bands, as indicated in table 5-3, but differ from field data by 10 percentage points or more on the intervisibility levels to 15 of the 36 ATM locations, as seen in table 5-8. Review of the detailed data indicates that model results are consistently too high or consistently too low over all approach route bands for 14 of these locations. In the remaining case, location 35, the model is too high on the first band and too low on the others. A potential explanation is that the model is depicting the general battlefield fairly well but is breaking down in the area containing the ATM positions.

c. Site B Results. Overall P_{LOS} results for each target position on Site B are contained in table 5-9. In selecting the 12 positions with the highest overall intervisibility levels, three errors would be made using the DYNTACS results, six errors using the CARMONETTE results, and 12 errors using the IUA results. If the same data were used to select the 12 positions with lowest overall intervisibility, three errors would be made using the DYNTACS data, six errors using CARMONETTE results, and all selections using IUA results would be in error. Discrimination between positions with relatively high or low intervisibility levels is a moot issue using the WES results, for which P_{LOS} over the entire set of 36 positions only ranges from .03 to .12. With respect to absolute differences between field and model P_{LOS}, DYNTACS results contain one serious disagreement and are within 5 percentage points of field results on 27 of the 36 positions. As indicated by its failure in properly discriminating between relatively high and low intervisibility positions, IUA results contain a marked inversion, with divergence from field results of from 12 to 25 percentage points on 14 positions, tending to report low levels when high levels exist and vice versa. CARMONETTE results seriously overstate intervisibility, with errors ranging up to 63 percentage points on 29 of the 36 positions. WES results seriously understate intervisibility, with disagreement of from 11 to 20 percentage points on 20 of the positions.

5-5. INTERVISIBILITY PATTERNS. Patterns of intervisibility between a specific target and a movement trace are reflected by intervisibility segments, that is, consecutive points along an approach route for which intervisibility to a given target exists and for which intervisibility is assumed to remain unbroken over the space between viewing points.

Table 5-9. P_{LOS} by ATM Position - Site B.

Panel Number	Exp 11.8	CARMONETTE	DYNTACS	IUA	WES
3	.29	.64	.27	.12	.12
2	.28	.64	.29	.13	.12
4	.28	.64	.28	.12	.10
5	.27	.39	.23	.11	.07
7	.26	.35	.30	.20	.06
1	.25	.61	.28	.08	.09
10	.25	.58	.31	.16	.06
6	.24	.64	.24	.09	.08
11	.24	.34	.27	.20	.08
12	.24	.34	.27	.20	.07
16	.24	.46	.23	.16	.09
36	.24	.49	.16	.18	.05
14	.22	.38	.24	.22	.07
17	.22	.46	.23	.18	.09
18	.21	.54	.20	.20	.07
19	.21	.52	.25	.24	.08
13	.19	.39	.23	.07	.08
15	.19	.46	.24	.09	.09
35	.19	.57	.15	.23	.06
33	.18	.35	.27	.14	.05
20	.17	.14	.18	.17	.06
21	.17	.36	.12	.15	.07
34	.17	.52	.18	.22	.07
22	.16	.34	.14	.18	.08
32	.15	.29	.21	.24	.05
23	.13	.18	.14	.25	.04
31	.12	.35	.20	.25	.04
9	.11	.12	.04	.05	.02
25	.10	.40	.09	.18	.03
30	.10	.35	.04	.17	.05
27	.09	.71	.06	.26	.03
8	.08	.12	.02	.18	.06
28	.07	.67	.07	.28	.04
29	.07	.67	.10	.30	.04
26	.06	.57	.10	.31	.03
24	.05	.63	.24	.30	.03

a. Descriptive Statistics. Descriptive statistics of the intervisibility segments as determined in Experiment 11.8 and by each model are contained in tables 5-10, 5-11, and 5-12 for the Site A Rapid Approach, Site A Covered and Concealed Approach, and Site B approach routes, respectively.

(1) Site A comparisons. None of the intervisibility models produced intervisibility segments similar to those reported in the field for Site A. DYNTACS results contain an excessive number of segments, with all descriptive statistics indicating that the typical sement is shorter than that measured in the field. Results for the other models contain a very low number of segments, generally fewer than half the number found in the field results, with all descriptive statistics indicating a typical segment to be much longer than was measured in the field. Further review of the data indicates that the most serious disagreement is found in the number of relatively short segments. As indicated in tables 5-10 and 5-11, the disagreement between model and field results is extreme in the number of segments under 35 meters in length (a single stake in the Experiment 11.8, DYNTACS, or WES results) and is less pronounced for segments 35 meters to 85 meters in length (segments of two or three stakes for Experiment 11.8, DYNTACS, or WES results). Agreement is better on the number of segments over 85 meters long (four or more consecutive stakes in Experiment 11.8, DYNTACS, or WES results). The DYNTACS and WES models used the same viewing points that were used in Experiment 11.8 (within the limits of the Experiment 11.8 position data accuracy), but IUA and CARMONETTE did not. For both IUA and CARMONETTE fewer points were used, resulting in a reasonable representation of the paths but providing viewing points that were typically 28 meters apart for IUA and 100 meters apart for CARMONETTE. Thus, it was impossible to establish a segment appreciably shorter than 100 meters with CARMONETTE. The different viewing positions used for IUA are not, however, considered to be at a sufficiently greater separation than those in the field to explain the lack of short segments in IUA results. The randomness used in DYNTACS determinations may provide a partial explanation of the apparent tendency of this model to break occurrences of intervisibility into a more isolated pattern than was reported in the field. If, for example, an approach route were moving toward a break in a tree line and one or several targets were in line with that route of advance, continuous line of sight to those targets would result in the field. The DYNTACS model, for each of 36 targets, would determine by a random draw whether the target could be seen through the tree line and could see the correct number of targets at each point on the movement trace. In each case, however, the random determination of intervisibility could be applied to a wrong target, resulting in the correct overall P_{LOS} represented as a number of isolated occurrences rather than a continuous string.

Table 5-10. Intervisibility Segments for Site A, Rapid Approach.

Item	Exp 11.8	DYNTACS (revised)	IUA (revised)	CARMONETTE	WES
Number of Segments	2943	5694	1140	1250	1503
Mean Length	180	100	435	556	307
Standard Deviation	290	163	400	610	362
First Quartile	25	24	110	120	50
Median	71	28	301	262	127
Third Quartile	175	89	626	786	434
90th Percentile	516	251	1035	1407	916
Longest Segment	2849	1683	1814	3521	1522
Segments Under 35m	942	2961	80	0	271
Segments 35-85	765	1253	148	0	300
Segments Over 85m	1236	1480	912	1250	932

Table 5-11. Intervisibility Segments for Site A, Covered and Concealed Approach

Item	Exp 11.8	DYNTACS (revised)	IUA (revised)	CARMONETTE	WES
Number of Segments	3155	5666	946	1306	1290
Mean Length	145	93	463	489	338
Standard Deviation	229	141	404	457	411
First Quartile	25	24	165	141	52
Median	51	29	364	262	194
Third Quartile	150	85	656	724	414
90th Percentile	376	252	982	1169	904
Longest Segment	1780	1559	1863	2024	1920
Segments Under 35m	1167	2946	57	0	219
Segments 35-85m	821	1304	104	0	207
Segments Over 85m	1167	1416	785	1306	864

Table 5-12. Intervisibility Segments for Site B.

Item	Exn 11.3	DYNTACS (revised)	IUA (revised)	CARMONETTE	WES
Number of Segments	2807	3405	647	1341	406
Mean Length	92	81	409	548	222
Standard Deviation	131	162	371	579	204
First Quartile	24	24	134	120	52
Median	48	25	344	320	172
Third Quartile	99	51	532	782	322
90th Percentile	222	146	773	1283	498
Longest Segment	1278	1545	1819	4222	967
Segments Under 35m	1263	2077	32	0	65
Segments 35-85m	758	817	84	0	73
Segments Over 85m	786	511	531	1341	268

(2) Site B comparison. The number of segments and mean segment length results with DYNTACS are similar to those from Experiment 11.8 for Site B. The other models exhibited the same type of disagreement found in the Site A results, with a much longer typical segment and many fewer segments than reported in the field. As was the case for Site A, DYNTACS results contain more very short segments than were reported in the field, and the other models are low on the number of short segments. The DYNTACS, IUA, and WES results contain a decrease in the total numbers of segments for Site B as compared to Site A, while the total number of segments remains relatively constant for the CARMONETTE and the experimental results.

b. Engagement Opportunities.

(1) General.

(a) Intervisibility segments are of particular interest in TETAM as representing opportunities for an ATM to engage a moving target vehicle. The potential for engaging a target on an intervisibility segment depends primarily on the firer to target range and associated missile flight time, rate of target movement, and detection/reaction time of the potential firer. To portray segment lengths required for engagement opportunities, a representative missile flight speed of 200 meters per second, vehicle movement rate of 3.5 meters per second (12.6 kph), and reaction times of 10, 25, and 50 seconds were used. These values give the segment lengths required for engagement contained in table 5-13.

(b) For comparison purposes, a segment shorter than that required with the 10-second reaction time is interpreted as giving "no" engagement opportunity, segments that would occur with a reaction time between 10 and 25 seconds represent "probable" engagement opportunities, and segments longer than that associated with the 50-second delay time are considered "definite" opportunities.

(2) Site A comparisons. With the 36 ATM positions and 10 approach routes used in the intervisibility experiment, there are 360 determinations of whether an engagement opportunity exists for most ATM-target range bands. The number of available determinations is reduced at ranges under 1,500 meters as some approach routes never came closer to certain ATM positions. The number of engagement opportunities contained in the field experiment and model results are shown in table 5-14 for the Rapid Approach routes on Site A and in table 5-15 for Covered and Concealed routes on Site A. None of the models is in close agreement with the field data over all ranges for each condition, nor is any one model consistently in closer agreement with the field data than the other models. Placing the greatest emphasis on ranges from 1,000 meters to 3,000 meters, which are of primary interest for the type

Table 5-13. Intervisibility Segment Length (M) Required for an Engagement Opportunity.

Detection/ Reaction Times (seconds)	Target Range (meters)							
	Over 4000	3500-4000	3000-3500	2500-3000	2000-2500	1500-2000	1000-1500	Under 1000
10	105	96	88	79	70	61	52	35
25	158	149	140	131	122	114	105	88
50	245	236	228	219	210	201	192	175

Table 5-14. Engagement Opportunities, Site A-Rapid Approach.

Data Source	Target Range (meters)							
	Over 4000	3500-4000	3000-3500	2500-3000	2000-2500	1500-2000	1000-1500	Under 1000
Exp 11.8								
Yes	26	3	49	107	124	110	164	201
Probable	21	11	23	32	50	72	40	22
Possible	8	12	28	24	44	50	26	18
No	305	334	260	197	142	128	111	52
DYNTACS								
Yes	33	26	49	78	102	100	122	158
Probable	25	15	27	37	50	58	45	40
Possible	5	8	29	51	48	43	39	35
No	297	311	255	194	160	159	135	60
IUA								
Yes	57	0	39	114	133	139	156	202
Probable	16	7	21	21	23	34	30	16
Possible	8	4	9	14	17	19	13	5
No	279	349	291	211	187	168	1	70
CARM								
Yes	85	34	62	138	186	184	187	196
Probable	21	24	33	29	32	48	25	19
Possible	34	35	36	23	31	7	9	3
No	220	267	229	170	111	121	120	75
WES								
Yes	73	0	20	84	115	99	159	201
Probable	10	3	24	30	33	47	33	25
Possible	11	2	25	34	24	32	17	15
No	266	355	291	212	188	182	132	52
Number of Observations	360	360	360	360	360	360	341	293

Table 5-15. Engagement Opportunities, Site A,
Covered and Concealed Routes.

Data Source	Target Range (meters)							
	Over 4000	3500-4000	3000-3500	2500-3000	2000-2500	1500-2000	1000-1500	Under 1000
Exp 11.8								
Yes	33	3	40	69	64	62	129	178
Probable	7	9	30	36	41	45	47	40
Possible	16	15	24	36	67	44	31	21
No	304	333	266	219	188	209	138	59
DYNTACS								
Yes	17	14	44	85	63	63	114	173
Probable	24	15	48	42	46	35	35	34
Possible	16	22	20	33	71	38	45	28
No	303	309	248	200	180	224	151	63
IUA								
Yes	56	0	37	101	76	59	129	222
Probable	23	6	26	26	32	42	27	15
Possible	9	10	14	12	26	29	18	12
No	272	344	283	221	226	230	171	49
CARM								
Yes	80	43	66	127	134	114	163	191
Probable	18	18	31	15	39	55	31	33
Possible	38	28	33	29	38	20	14	4
No	224	271	230	189	149	171	137	70
WES								
Yes	79	0	23	63	53	66	147	214
Probable	17	3	39	37	27	34	27	17
Possible	4	5	18	45	39	27	12	6
No	260	352	280	215	241	233	159	61
Number of Observations	360	360	360	360	360	360	345	298

weapons under consideration, CARMONETTE is the poorest of the four models, consistently overstating the number of engagement opportunities. Even within this restricted range band, none of the other models is in consistent agreement with the field data, although each does match the field data well in at least one instance on the middle range bands.

(3) Site B comparisons. Engagement opportunities inferred from the Site B intervisibility data are contained in table 5-16. In this case, CARMONETTE results are in gross disagreement with any other data. Of the other three models, DYNTACS results agree well with those of Experiment 11.8 at ranges beyond 1,000 meters and are reasonably consistent under 1,000 meters. WES results understate the number of opportunities at ranges under 1,500 meters to an unacceptable level, while IUA results overstate the opportunities at the same ranges to a similar level.

Table 5-16. Engagement Opportunities, Site B.

Data Source	Target Range (meters)							
	Over 4000	3500-4000	3000-3500	2500-3000	2000-2500	1500-2000	1000-1500	Under 1000
Exp 11.8								
Yes	0	0	0	4	12	16	32	186
Probable	0	0	1	1	23	18	32	83
Possible	0	0	0	7	14	14	54	35
No	20	182	346	348	311	312	242	29
DYNTACS								
Yes	0	0	0	1	13	27	39	183
Probable	0	0	1	2	15	8	31	61
Possible	0	0	1	2	20	16	49	66
No	20	182	345	355	312	309	241	23
IUA								
Yes	0	0	0	0	4	12	55	299
Probable	0	0	0	1	8	11	42	9
Possible	0	0	0	4	9	9	20	8
No	20	182	347	355	339	328	243	17
CARM								
Yes	0	0	23	109	137	115	205	322
Probable	0	1	16	30	46	62	40	6
Possible	0	0	30	64	41	50	32	0
No	20	181	278	157	136	133	83	5
WES								
Yes	0	0	0	0	1	8	1	165
Probable	0	0	1	0	1	4	6	39
Possible	0	0	1	0	2	4	7	22
No	20	182	345	360	356	344	346	107
Number of Observations	20	182	347	360	360	360	360	333

CHAPTER 6

SIDE ANALYSIS

6-1. GENERAL. In addition to the basic comparisons presented in chapter 5, several side analyses were conducted to investigate the stability of model results and comparison procedures under changes of selected parameters. These analyses are discussed in the following paragraphs.

6-2. DYNTACS RANDOM NUMBER SEQUENCE.

a. Requirement. The revised DYNTACS intervisibility model contains a random treatment of vegetation. Additionally, the random treatment of minor elevation variances about the modeled terrain profile is contained in both the original and revised DYNTACS intervisibility models. Thus, determinations of intervisibility using DYNTACS will depend not only upon the terrain-descriptive input data but also upon a sequence of pseudo-random numbers generated within the model. This analysis was conducted to investigate the stability of DYNTACS results using different sequences of pseudo-random numbers.

b. Approach. For each of the three experimental conditions, four replications of the DYNTACS intervisibility determinations were made. These replications used four random number seeds that were known to cause the random number generator within the model to produce different, statistically acceptable, sequences of pseudo-random numbers. The four replications for each condition were then compared using the same intervisibility level comparisons made in the basic comparisons discussed in chapter 5.

c. Results. To the two decimal places used in this study, overall P_{LOS} did not change over the four replications. Intervisibility levels for approach route bands and for individual ATM positions varied by 1 or 2 percentage points over four replications. A maximum variation of 3 percentage points was noted twice under each condition, and a lack of variation over the four replications was noted five or six times on each Site A condition and nine times on the Site B condition. It was concluded that, for the purposes of the intervisibility comparisons, the DYNTACS random number sequence would have no effect on any findings or conclusions.

6-3. OBSERVER/PANEL HEIGHT VARIATIONS.

a. Requirement. The basic comparisons were carried out for one combination of observer and target panel height. In model applications,

it would be necessary to discriminate among weapon systems of differing heights and various degrees of defilade available to the weapons. This would be reflected by the other observer/panel height combinations for which data were collected.

b. Approach. This comparison used the same intervisibility levels (P_{LOS}) used in the basic comparisons. First, the extent to which variations in observer/panel height combinations caused a difference in intervisibility levels in the field data was established. Then, the effect of the same height combination changes on model results was established. Data for different height combinations with the revised IUA model were not available, so the results of the original IUA model runs were used in this comparison. Although it may be a reasonable assumption that this will reflect the general tendency of the revised IUA approach, these IUA results should be viewed with caution. All height combination comparisons are limited to the Site A, Rapid Approach data.

c. Results. Table 6-1, showing the differences in overall P_{LOS} for various height combinations, reflects the general magnitude of the field and model data sensitivity to changes in these parameters. In absolute terms, the different target panel heights produce a 1 to 3 percentage point difference in overall P_{LOS}, and differences in observer height produce a 2 to 8 percentage point difference. (Recall that the listed IUA results, which are for the original model, may not reflect the revised model.) Review of the detailed data allows the following observations.

(1) Changes in Experiment 11.8 data are evenly spread over all targets. For example, the overall high-high to low-low change of 4 percentage points is reflected in a change of from 3 to 5 percentage points on 27 of the 36 target panels. Of the remaining panels, two changes of 1 percentage point, five of 2 percentage points, and one each of 6 and 7 percentage points are noted. The relatively small changes are found, with one exception, for panels that had a relatively low level of intervisibility in the basic comparisons (P_{LOS} less than .15) and probably represent some "bottoming out" of the data. The changes are greater in the closest five bands (4 to 6 percentage points in bands A, B, C, D, and E and 1 to 2 points in bands F, G, and H), which again appears to be a "bottoming out" tendency.

(2) Changes in CARMONETTE results are evenly spread over targets, with the overall high-high to low-low difference of 4 percentage points being reflected by changes of from 2 to 7 points on 31 of the 36 panels. Of the remaining panels, three show no change, panel 16 shows a change of 11 percentage points, and panel 17 shows a change of 15 points. CARMONETTE results reflect the tendency to have greater changes in the closer bands to a slightly greater degree than in the experimental data.

Table 6-1. Overall P_{LOS} and Different Height Combinations - Site A, Rapid Approach

Height		Data Source				
Observer	Panel	Exp 11.8	CAR-MONETTE	DYNTACS (revised)	IUA (original)	WES
High (2.84m)	High (2.95m)	.29	.37	.31	.42	.25
High	Low (1.12m)	.28	.35	.28	.40	.23
Low (1.22m)	High	.26	.35	.25	.34	.22
Low	Low	.25	.33	.22	.32	.21

(3) DYNTACS results contain a noticeably, and probably significantly, greater level of sensitivity to height combinations than is found in the field data. These results also contain more pronounced patterns than are found in the data for the other models. Considering only change in observer height, from the high-high to low-high combinations, an overall P_{LOS} difference of 6 percentage points is noted. On a target by target basis, this change reflects individual differences of from 1 to 10 percentage points, with a clear tendency for the greater changes to be associated with targets having greater overall intervisibility levels and smaller changes with targets having lower overall intervisibility. Considering only changes in target panel height, an overall P_{LOS} change of 3 percentage points is noted between the low-high and low-low combinations. This reflects two phenomena. First, there is a stable change of 1 percentage point for 15 of the targets and of 1 to 3 percentage points for 29 of the 36 targets. The remaining seven targets include three with a 5 percentage point change, two with a 6 percentage point change, one with a 7 percentage point change, and one with a 13 percentage point change. Each of these targets was located at the edge of a steep dropoff on the ridgeline and within an area of thick vegetation. The same pattern is seen in comparing the DYNTACS high-high and high-low combinations. Changes in the closest five bands tended to be two to three times greater than those in the farther bands, as was noted for the field and CARMONETTE results.

(4) Changes in the WES model results are evenly spread over all targets. The overall high-high to low-low change of 4 percentage points reflects a change of from 3 to 5 percentage points on 26 of the 36 targets (20 of these were contained in the set of 27 targets with the same size change in the field data). Of the remaining 10 targets, three have a smaller change and seven show a greater change, ranging up to 9 percentage points. The WES changes appear to be concentrated in the closer battlefield bands, with differences of 8 and 10 percentage points in bands A and B, 5 percentage points in bands C and D, 3 percentage points differences in bands E and G, and no difference and a 1 point difference in bands F and H.

(5) Detailed data were not available for review of the IUA differences.

6-4. CURVATURE OF THE EARTH. In an effort to explain the tendency of the combat simulation to overestimate intervisibility at longer ranges, a curvature of the earth correction was put into the DYNTACS intervisibility algorithm. The correction changed fewer than 1 percent of the intervisibility determinations for the Site A-Rapid Approach condition, which was judged to be inconsequential.

6-5. ENGAGEMENT OPPORTUNITIES FOR HIGHER TARGET SPEED.

a. Requirement. The analysis of engagement opportunities contained in chapter 5 was performed using a typical target vehicle speed of 3.5 meters per second. Review of a later phase of Experiment 11.8 indicates that, in some instances, this may be slower than typical speeds; so the analysis was repeated with a 5 meter per second vehicle speed.

b. Results. Results of this comparison were consistent with those of the basic comparison presented in chapter 5. None of the models was in agreement with the field data for Site A conditions. DYNTACS results agreed moderately well with the field data for Site B, and the other models maintained their distinctive patterns of disagreement discussed in chapter 5.

6-6. EUROPEAN VEGETATION.

a. Requirement. A major model problem in representing intervisibility is the portrayal of the type of vegetation found on the Hunter-Liggett Military Reservation (HLMR) sites. The general model approach is to portray only large and dense stands of trees. The HLMR site, however, contained a significant number of large trees that were not in dense stands but nevertheless had a pronounced effect on the intervisibility characteristics of the site. An attempt to portray this condition by incorporating a probabilistic treatment of vegetation in the DYNTACS model was moderately successful. The question arises as to whether this effect will also be found on typical sites located in Europe, since past and current applications of the models generally involve a European scenario.

b. Approach. Aerial photographs of 11 European sites covering four locations in the Fulda area, one location in the Hohenfels area, and six locations in the North German Plains (NGP) were available at CDEC. These sites were used in the Europe Phase (Phase IE) of the TETAM Field Experiment, and the interested reader may find specific map coordinates and a general description of each site in the CDEC field experiment reports (reference 1c). Photography for one site, 2B in the North German Plain, was not available. These available photographs were reviewed by the same individual who had prepared the input data used in the DYNTACS probabilistic vegetation treatment, with the specific goal of locating vegetation similar to that found on the HLMR site, that is, stands of large but scattered trees. In the review, no attempt was made to locate those portions of the photography showing exact positions used in TETAM Phase IE work, nor was any emphasis placed on portions of the photography based on tactical considerations, such as avenues of approach or potential defensive positions. The review was accomplished using a simple magnifying glass.

c. <u>Results</u>.

(1) The vegetation patterns noted at HLMR were also noted to a considerable extent on the Hohenfels site (Site 6F in the CDEC final report) and on one of the North German Plain sites (3B). The HLMR patterns were not found on site 5B (North German Plain), 1F, or 3F (both Fulda). The remaining six sites contained the HLMR pattern only in isolated spots.

(2) Each site did contain significant areas of dense vegetation that would be treated reasonably well by the deterministic, opaque mass, treatment used in the models.

(3) A significant number of linear tree lines along roads and waterways were noted. Model problems would occur with these since their coded width would necessarily be greater than their actual width. Thus, representation would probably be acceptable for a line of sight normal to the tree line but would be poor for line of sight close in to and parallel to the line. Additionally, a significant number of built up areas were noted.

CHAPTER 7

LESSONS LEARNED

7-1. GENERAL. In performing the work described in the preceding chapters the study team learned a number of lessons related to the preparation, application, and validation of the three models. These lessons are included here in the hope that they may benefit current and prospective model users.

7-2. LESSONS IN MODEL PREPARATION. The intervisibility comparisons used the models' terrain representation and a limited portion of the models' logic. Thus, lessons learned in preparing the models for an application are related to the preparation of terrain data. There are two schools of thought on the requirement for having in the models terrain data that accurately describe specific real world terrain sites (likely battlefields) as opposed to terrain data describing nonexistent but ostensibly representative (theoretical) terrain. This issue of whether there is a requirement for the preparation of highly accurate real world terrain data for normal applications was not resolved. The TETAM validation effort required the preparation of terrain data describing the real world sites upon which the field experiments were conducted.

a. Level of Effort. The preparation of highly accurate terrain data for any of the models is a laborious and time consuming task. The impression persists that DYNTACS uses "digitized terrain" and that the preparation of DYNTACS terrain data is not the major undertaking that it is for the other models. Digitized elevation data are used in DYNTACS, but all other terrain inputs (a considerable number) are prepared by hand. About 2 manmonths are required to prepare terrain data for any one of the models. These data must be prepared by personnel having a detailed understanding of how the data are to be used in the model and the ability to read both military mapsheets and aerial photographs with facility.

b. Lead Time. Data sources required for preparation of accurate terrain inputs include military mapsheets; aerial photographs; digitized elevation tapes (essential for DYNTACS, useful for CARMONETTE); and soil, terrain roughness, and vegetation overlays. In addition, one or more on-site inspections of the actual terrain is desirable during the preparation process. With the exception of military mapsheets, the procurement of these items requires considerable lead time, so model application requiring terrain data preparation must be planned for several months in advance. Mapsheets of a scale large enough for extracting elevations and their locations by hand (1/25,000 or larger) are becoming increasingly difficult to obtain.

c. Accuracy of Elevation Data. The accuracy of elevations used in calculations during a typical model run is determined by the accuracy of

the sources from which terrain inputs are prepared, the accuracy inherent in the procedures for preparing data from these sources for model use, and the accuracy inherent in the methodology for selecting and applying these data in model computations.

(1) Accuracy of source data. Digitized elevation data are normally developed from standard Army mapsheets, with elevation data between contour intervals being derived through interpolation. Thus, differences in accuracy between digitized and hand-prepared elevations derive from differences in the accuracy with which these data are extracted from the same source.

(2) Processing accuracy. The accuracy with which these source data are prepared for use in the models is also important. The free triangle approach used in IUA introduces both a potential for human error in extracting the elevation data from a source and a high degree of subjectivity in selecting the points to be used. The other models, with square grid systems, avoid the subjectivity and do (or could with relative ease) provide for the automated processing of these data. Automation is, however, no panacea. In a typical DYNTACS application, for example, accepted procedures for the transition from the original digitized elevation data, as typically provided by the Defense Mapping Agency, to data for use by the model can involve three major interpolative adjustments of the entire data base. The effects of these can be minimized, but nowhere in the model literature is a potential user warned of this problem.

(3) Application accuracy. Each model uses the input elevation data to estimate the elevation of any arbitrarily selected point on the battlefield. In CARMONETTE the elevation datum at the center of each (100 meter) square grid is applied over the entire grid; the othe models use an interpolation scheme. No explicit study of the accuracy with which discrete elevations are estimated was conducted. It is obvious, however, that the CARMONETTE approach will have the greatest overall inaccuracy; the other approaches, being of an interpolative nature, will be of increasing accuracy as the spacing between data points is reduced. Thus, there is no reason to doubt that the DYNTACS scheme is more accurate than that used in IUA and that the WES scheme, with a 25-meter grid system, is the most accurate of the four models. However, the major lesson inferred from the comparison results is that none of the approaches is remarkably accurate.

d. Accuracy of Vegetation Data. Whereas the accuracy of elevation as available for and used by the models is questionable, the accuracy of vegetation data is unquestionably bad. The best source data are found in aerial photography of the area; but, considering seasonal variation and the transitory nature of vegetation, maintenance of sufficiently accurate and current photocoverage is problematic. The translation from source data to data used by the models is subjective in the

extreme. Finally, consideration of the effects of vegetation within the models is highly simplistic, with DYNTACS being less so only when viewed relative to the other models.

e. Quality Assurance. At the inception of the TETAM project, reasonable procedures for verifying the accuracy of terrain inputs existed only for the DYNTACS model, with a number of computer programs having been developed for DYNTACS that produced graphic representations (contour maps, shaded vegetation areas, etc.) of the terrain inputs. These graphics make the detection of most types of major errors likely. Some of these procedures have since been adapted for use with the CARMONETTE and IUA models.

7-3. LESSONS IN MODEL APPLICATIONS. Two specific lessons related to applications of the three combat models are discussed below.

a. General Purpose Terrain. Even though the intention may have been to develop terrain data bases of general usefulness, only a limited number of specific terrain data bases have been developed for particular model applications. Because of the effort required in developing data for new terrain areas, these same terrain data have been used in one model application after another. The importance of these two observations taken together is illustrated by the fact that in all three models line of sight cannot exist to positions located in certain types of vegetation even though by map analysis these positions might be specifically selected for long range observation and fields of fire. To avoid this obvious mistake the preparer of terrain data must know during data preparation the general area in which weapons are to be emplaced. Thus, with the concept of general purpose terrain, the terrain data must be carefully reviewed for every model application by knowledgeable model experts to determine whether revisions to these data are required for the scenario to be played.

b. Model Scenario Development. During the intervisibility study it was learned that establishing defender weapon locations in the models by (mathematically) converting UTM coordinates to model coordinates often did not produce results desirable for model applications. In some cases, the geometric model representations of terrain surface and vegetation precluded model weapons from realizing the good observation and fields of fire enjoyed by their field experiment counterparts. This can often be corrected by changing slightly the location or height of defender weapons in the models. A computer program is available for DYNTACS that computes and displays all areas of the battlefield that can be observed from a specific defender (or any other) location. Both IUA and CARMONETTE also provide some information on LOS. The lesson is that some capability exists within each model to check the amounts of intervisibility produced for specific battlefield locations, and these capabilities should be exercised so that weapon locations in the models are established based upon the extent to which their desired intervisibility characteristics are actually portrayed within the model.

7-4. LESSONS IN MODEL VERIFICATION.

a. Simultaneity of Experimentation. The intervisibility portions of Experiment 11.8 were completed over a year before model validation analysis was begun. In the interim, the experimental sites had been used for several different applications, the personnel actually conducting the experiment had gone on to other assignments, and much of the background information gathered and materials used in the course of the experiment were discarded. The validation effort, carried on some half a continent removed from the experimental sites, perforce was conducted with less than a full knowledge of what really took place in the field and with almost no ability to check any hypothesis as to the causes of difference between model and field results. Future model validation efforts would be much improved if the basis for comparison, the model results, and the actual comparisons were generated as an integral effort. Although this would require some commitment of experimental resources to an evolutionary schedule paced by the validation, the benefit of allowing differences between field and model results to be explored, more fully understood, and, hopefully, resolved, might well be worth the cost.

b. Validation Criteria. Widely acceptable criteria upon which to base a final determination of model validity remain undefined. The approach used in the intervisibility comparisons evolved to one of presenting comparisons supported by that part of the data in which there was a reasonable level of confidence and drawing subjective conclusions as to the degree of model agreement with field results. Every effort was made to present sufficient information to allow the independent reviewer to draw his own conclusions. It was found, after considerable effort had gone into attempting detailed comparisons, that first emphasis should have been placed on such gross measures as overall probability of line of sight, thus obviating work that stood little chance of furthering an understanding of the apparent differences. The lesson is that first comparisons should be made on a very gross level, allowing some judgment as to whether the appropriate next step should be more detailed comparisons or gross remedial actions.

CHAPTER 8

FINDINGS AND CONCLUSIONS

8-1. GENERAL. The purpose of this chapter is to identify the principal findings of the intervisibility study, to discuss the interrelations of certain of these findings, and to present the study conclusions.

a. Frame of Reference. The intervisibility comparisons conducted as part of the TETAM Model Verification Study had the goal of determining the extent to which the representation of intervisibility within CARMONETTE, DYNTACS, and IUA agree with the intervisibility data collected in Experiment 11.8. With the general lack of model and field agreement found in the original intervisibility comparisons (reference 5), the additional goals of improving the degree of model/field agreement and of investigating the capability of the WES model were added.

b. Major Limitations. Several major limitations of the comparisons and of their general applicability must be held in mind when reviewing the findings reported below.

(1) CARMONETTE data limitation. The inability of the Concepts Analysis Agency to extend their commitment upon expiration of the originally agreed upon study period forces a lack of balance in the comparisons. DYNTACS and IUA results discussed in this volume are those attained after modifications were made to the original model logic and terrain data. CARMONETTE results, on the other hand, are limited to those attained without benefit of any corrective actions. It is possible that the degree of CARMONETTE agreement with field results could be improved with relatively minor changes to the model or data.

(2) Intervisibility within the combat simulation structure. These comparisons center upon intervisibility as an isolated phenomenon. Within the context of the overall TETAM effort, intervisibility is of no great interest in itself. Rather, intervisibility is considered a critial phenomenon because it is a logical prerequisite to the processes of target detection and engagement by direct fire weapons and ground-observer-controlled indirect fire weapons. Thus, the degree to which a model is capable of representing intervisibility is of interest and is addressed in this report, but the way such a capability is incorporated into and used within the overall simulation model remains at issue and will be treated as part of the dynamic battle comparisons (reference 6).

(3) Limited basis of comparison. The TETAM intervisibility comparisons are limited to the realization of intervisibility as reflected by an experimental data base collected within one valley of the Hunter-Liggett Military Reservation. The potential for error in this data base has been discussed. The actual extent and nature of error in this data base remains unknown. In addition to the question of experimental error, the ability to generalize the results of these

comparisons is questionable on two grounds. First, the degree to which the terrain site used is representative of the areas and scenarios of interest for applications of the combat models is not known. Second, the philosophy apparently underlying the intervisibility portions of Experiment 11.8, and perforce followed in the comparisons, is that intervisibility is primarily a terrain-driven phenomenon. The experiment was conducted to obtain, for each experimental site, data from points that provide essentially uniform coverage of the total site. An alternate philosophy, particularly in the context of the small unit battles considered in TETAM, is that intervisibility is controlled by the combatant and his use of the terrain. Under this philosophy, the pertinent issue would have been how well the models portray that portion of a site the combatant would actually use and how well this region could be discriminated from the remainder of the site.

(4) Pragmatic approach to modifications. The modifications made to DYNTACS and IUA logic or data were made on a highly pragmatic basis in the sense that, if a change appeared to be logically sound and if it drove the model results closer to the field results, it was considered an appropriate change. It is possible that the modifications did not solve the initial problem but simply added a compensating error.

8-2. FIELD EXPERIMENT RESULTS. The approach taken in this study required that the models simulate as closely as possible the actual conditions under which Experiment 11.8 was conducted so that intervisibility data produced by the models could be compared directly to corresponding field data. These data comparisons were then to provide a basis for inferences concerning model validity. This approach proved difficult to implement as a number of uncertainties regarding the quality of the field data came to light. Review of the experimental data and procedures led to a series of preliminary conclusions as to the ability to infer model validity through comparisons to these data. The more critical of these include:

a. The data collected in Experiment 11.8 are judged to be of sufficient quality to support strong validation conclusions only with respect to general intervisibility levels between the respective defensive areas and areas containing the approach paths.

b. Limitations of the quality control procedures used in Experiment 11.8 and the potential for random error throughout the experimental data indicate that conclusions based on the effect of different target/observer heights on intervisibility, the nature of LOS interruptions, or the definition of continuous LOS segments should be viewed with caution.

c. Given a potential for detection errors in the field, if there is a consistent overall bias in the Experiment 11.8 data, it will tend to be an understatement of intervisibility, particularly at longer ranges.

d. There is no apparent basis for the quantification of error rates or for the assignment of a level of confidence to the experimental data.

8-3. CARMONETTE FINDINGS.

a. Intervisibility Level Comparisons.

(1) The available Site B results for CARMONETTE were produced using terrain data derived from that used originally for DYNTACS and known to permit excessive intervisibility. The Site A results, however, were produced with terrain data developed specifically for CARMONETTE by CAA personnel familiar with the model. As such, only the Site A results are considered representative of the model's true capability.

(2) The Site A intervisibility level comparisons indicate a tendency for CARMONETTE to depict significantly greater levels of intervisibility than were recorded in the field. Intervisibility levels from over half the ATM positions were significantly different from the field results, with instances of extremely low as well as extremely high intervisibility levels being found in the CARMONETTE results.

(3) The Site A ATM positions were located at the foot, forward slope, and crest of a steep ridgeline. The ridge rises over 200 feet above the valley floor in less than 200 meters horizontal distance. Since CARMONETTE was exercised with a 100-meter grid cell and CARMONETTE assigns a single elevation throughout each cell (more correctly, CARMONETTE treats each element as being located at the center of a cell), it is apparent that insufficient resolution was available in depicting the elevations at this ridge. An obvious (but untested) hypothesis is that CARMONETTE depiction of intervisibility would, in this case, be improved by increased terrain elevation resolution. This might be accomplished by going to a smaller grid size or by incorporating a more precise location of individual elements and interpolating elevations on the 100-meter grid already available.

b. Intervisibility Pattern Comparisons. Typical intervisibility segments derived from CARMONETTE results are longer than those derived from the field data. This result is not given heavy weight, considering the oversensitivity of segment-oriented analysis to potential field data error, but it is true that short segments (under 100 meters) are impossible with CARMONETTE as it was exercised. Increasing terrain resolution, as discussed above, would at least make shorter segments possible with this model.

c. Preliminary Conclusions. Available CARMONETTE results do not provide an acceptable degree of agreement with Experiment 11.8 data in the representation of intervisibility on Site A, HLMR.

8-4. DYNTACS FINDINGS.

a. Intervisibility Level Comparisons.

(1) DYNTACS model results were found to be at an acceptable level of agreement with the field data in representing intervisibility levels for Site B.

(2) Site A results with the revised DYNTACS are mixed. Acceptable agreement with the field data is found with the exception of intervisibility levels associated with certain individual ATM positions. The problem with these positions is emphasized by the fact that DYNTACS results exhibit an oversensitivity to target height (when compared to the experimental data) at these positions. These positions are typified by their locations at the edge of steep slopes and significant close-in and dense vegetation. The result appears to be (in the field) a highly compartmented view of the battlefield from these positions, with long-reaching intervisibility over some sectors of view but with intervening sectors of total blockage. The model appears incapable of handling this condition.

b. Intervisibility Pattern Comparisons. The introduction of a probabilistic treatment of significant vegetation into DYNTACS had an apparent overcorrecting effect on the number and typical length of line-of-sight segments inferred from the model results. When compared with the intervisibility results from Experiment 11.8, this treatment tends to produce too many short segments. However, subsequent field experimentation in the HELAST II and HELLFIRE studies (references 8 and 9) has indicated that these short segment lengths may exist. These studies have indicated that the discrete 25-meter method of terrain measurement used during Experiment 11.8 may not be of sufficient resolution to record the short segment lengths and that the segment lengths do in fact often exist. A potentially fruitful area for further investigation would be to develop a middle-ground approach, neither deterministic nor freely random. With such an approach, once an intervisibility corridor through a vegetated area was (probabilistically) established, it would be maintained as long as movement of one of the LOS endpoints was through that corridor.

c. Preliminary Conclusions. The revised DYNTACS terrain representation of the HLMR site is acceptable for use in the TETAM free-play comparisons. The general approach of introducing probabilistic vegetation into DYNTACS is considered appropriate for other model applications, but the details of this change as implemented in TETAM must be viewed as exploratory.

8-5. IUA FINDINGS.

a. Intervisibility Level Comparisons.

(1) The intervisibility level results produced by the revised IUA model for Site A are generally at an acceptable level of agreement with the experimental data. There are, however, a small number of ATM positions (5 of 36) for which an extreme divergence from model results is noted. No distinctive pattern of locations on the Site A ridge, close-in vegetation, or compartmentalized intervisibility has been detected as being common to these targets. Additionally, IUA tends to overstate intervisibility at relatively short ranges.

(2) Site B intervisibility level results obtained with the IUA model seriously disagree with the field data. A marked inversion is found in the two data sets. Those ATM positions having relatively high intervisibility levels in the field data have relatively low levels in the IUA results and vice versa. No explanation of this phenomenon has been found.

b. Intervisibility Pattern Comparisons. The IUA model produced significantly fewer line-of-sight segments than were found in the field data, with a marked lack of relatively short segments. The impact of this finding is not clear since segment-oriented measures are considered overly sensitive to potential error in the basis of comparison.

c. Preliminary Conclusions. The revised IUA representation of intervisibility is acceptable for use in the TETAM free play comparisons provided that these are limited to Site A conditions and the defender positions actually used are reviewed for the occasional serious misrepresentation of a specific position that was noted for this model. The modifications made to this model are considered necessary (but may not be sufficient) for reasonable intervisibility representation on any terrain site.

8-6. WES MODEL FINDINGS.

a. Intervisibility Level Comparisons.

(1) The intervisibility level comparisons for Site A indicate a tendency for the WES model to understate the level of intervisibility from the middle approach route bands. Overall intervisibility levels to the individual ATM positions in the field are, however, reproduced well by the WES model. This result may be attributable to problems in the terrain data used rather than model logic. This hypothesis is based on the observation that the terrain at the defensive position would be considered critical by someone familiar with the site and might have been coded with more precision or diligence than the remainder of the terrain site.

(2) The WES model results for Site B contain a serious understatement of intervisibility levels when compared to field results.

b. Intervisibility Pattern Comparisons. The WES model results produce too few segments when compared to field results. The discrepancy is most obvious in a lack of short segments but is also noted for longer segment lengths. The lack of short segments makes typical segment lengths from this model much longer than those of the field data.

c. Preliminary Conclusions. Applying the same criterion as was used for the other models, the WES results would be judged sufficient

for use in free-play comparisons if the WES model were part of a larger combat simulation. This would be limited to Site A conditions; and a tendency to be underactive, because of low intervisibility at medium ranges, would have to be watched.

8-7. DISCUSSION.

a. Orientation. There are four basic questions that are considered critical to the model verification effort and upon which these comparisons shed some light. These include:

(1) Do the combat models (CARMONETTE, DYNTACS, and IUA) provide a sufficient representation of the intervisibility conditions at HLMR for meaningful results to be obtained in comparing the outcomes of free-play battles as simulated in the models with the data from the force-on-force field experiments?

(2) Do the combat models represent intervisibility adequately to insure that, in typical model applications, flaws in the intervisibility representation do not drive the models to erroneous results?

(3) Are model modifications to improve the representation of intervisibility indicated

(4) Does the WES model provide a substantial improvement in the representation of intervisibility over that provided by the combat simulations?

b. Sufficiency for Continued TETAM Verification.

(1) The revised DYNTACS and IUA representationf of intervisibility have been judged sufficient for continued TETAM verification work, and the results attained with the original CARMONETTE representation have been judged insufficient. There is bias in these judgments in the sense that the CARMONETTE model and data were not available for the logic and data "tuning" that proved necessary to achievment of acceptable performance from the other models. Even after modifications, the DYNTACS and IUA results are acceptable only under the conditions that IUA be limited to Site A and that further verification work with both models include continued scrutiny of individual ATM position intervisibility, which can in some cases be poorly represented. CARMONETTE results (for Site A) were judged unacceptable only because the extreme disagreement from field data for specific ATM positions was so widespread, showing up for over half of the positions.

(2) The judgments as to sufficiency were made solely on the basis of the intervisibility level comparisons. The study team was unable to determine the significance of the observed differences in intervisibility segments inferred from model and field results. The assumption that intervisibility conditions on a movement trace continue unchanged

between two arbitrarily selected sample points is, on the surface, invalid. The extent to which the assumption leads to serious error depends on the spacing between points. Within actual model applications (as opposed to the isolated exercise of intervisibility routines used for intervisibility comparisons), samples typically would be made at 30-meter intervals for IUA and 100-meter intervals for CARMONETTE. The DYNTACS samples that would affect detection are made after each model movement event and depend on the distance traveled in the event. With typical movement rates of 5 meters per second, and 30-second move events, this would lead to a typical 150-meter interval between samples. From this point of view, it is possible that DYNTACS, with potentially the best representation of intervisibility when studied in isolation, actually makes the worst use of intervisibility within the overall simulation due to insufficient sampling. It is expected that the free-play comparisons will shed some light on this issue.

c. Sufficiency for Typical Applications. Based on the results and experiences of the TETAM Model Verification Study, model representation of intervisibility is inadequate for model applications for which ground truth is critical.

(1) Sufficiency for further TETAM verification work was obtained only with limitations and only after recourse to tuning of the models and data. This tuning depended on the availability of the experimental data as a target toward which model results could be driven. Such data are not available for typical model applications.

(2) Several arguments could be developed to support a counter-claim that the models are good enough for typical applications. For example, it could be argued that typical applications use a specific piece of terrain as being representative of a larger region; thus, it is not critical to represent a particular piece of ground as long as the general characteristics of the region of interest are being portrayed. Alternatively, it could be argued that the terrain sites at HLMR are in some sense pathological; thus, the lack of comparability is not indicative of general model weakness. Such arguments are beyond the scope of this study. Beyond the review of selected sites in Europe, for which the same vegetation problem seen at HLMR was found to exist in some instances, no attempt was made to address such issues. The conclusion, thus, must be restricted since the importance of representing ground truth was not addressed.

d. Model Revisions.

(1) The IUA revision allowing for calculation of intervisibility to individual defender positions should be incorporated into all future versions and applications of this model. The original approach of calculating intervisibility to objective points apparently had no justification beyond programming ease and a saving in computer time and core storage. This is insufficient justification for the error introduced by the original approach.

(2) The IUA revision that uses vegetation heights as entered into the data base (rather than averaging the heights for contiguous triangles) should be incorporated into future model versions and applications. The original averaging approach has no apparent justification, and its effect is to negate much of the input data.

(3) Some modification of the treatment of vegetation in DYNTACS is required. The revisions made for TETAM model verification are simply a recognition that a stand of trees need not be impenetrably dense to have an effect on intervisibility. A change of this general nature should be maintained in the model; however, the revision made for TETAM is not considered ideal. It appears to have introduced more randomness to the representation than is appropriate, and it partially overlaps the model's existing concealment logic.

(4) The level of terrain resolution in CARMONETTE is considered insufficient to deal with such geographic features as the steep ridgeline on which Site A ATM positions are located. Using smaller grid cells could improve the situation. It is preferable that elevations for specific points be interpolated from the sample data contained in the model, rather than letting a single data point apply directly over the entire cell, as CARMONETTE does. Such a change may imply drastic modification to the total model logic, since CARMONETTE is designed around the assumption that it is sufficient to locate elements to the nearest terrain cell.

e. WES Model Potential. The WES model was viewed only in terms of its potential for incorporation into the combat simulations. The results attained with the WES model do not provide a substantially better match to the field data than can be attained with the terrain representation of the combat simulations. Thus, it must be concluded that incorporation of the WES model into the combat simulations will not produce any marked improvement in the simulations. There is no indication that the WES model representation is any worse than that achieved in the combat simulations, but it is not appreciably better.

f. Implications. Several implications as to the capability and application of terrain models similar to those investigated are apparent. It should be recalled that the four models reviewed share the same general approach, differing primarily in their levels of resolution and mathematical or programming details of implementation.

(1) It has be concluded that the approach embodied in these models does not provide a good approximation to ground truth. The degree to which ground truth is a valid modeling requirement has not been established. It appears to be a commendable goal and was important for the purposes of further progress within this study effort. However, the degree of fidelity with which terrain must be represented for more typical model applications remains an open issue.

(2) The increased resolution in landform representation provided by the WES model does appear to be beneficial in a region of steep gradients. With a constant size grid system, however, increases in resolution have severe practical limitations in terms of computer space required. A variable-size grid system, although it would increase program complexity, might be worth investigation.

(3) The options embodied in the original models of either treating areas of vegetation as impenetrable or ignoring them are insufficient. A probabilistic approach similar to that introduced to DYNTACS for this study appears appropriate. Further work is indicated, but the approach should be broadened to allow a more compatible interface with concealment as represented in the various models. There is no clear distinction, in any of the combat simulations, where data for cover provided by major vegetation should end and different data for concealment (provided by other vegetation) should begin. The boundary between these factors should be recognized as being poorly defined in the real world and may imply that the model definitions of the two as distinct processes are arbitrary.

8-8. CONCLUSIONS.

a. Intervisibility results obtained with the modified DYNTACS and IUA models are sufficient to allow further TETAM model verification investigations into other aspects of these models.

b. The CARMONETTE intervisibility results available for this analysis are not sufficient to justify TETAM model verification work on other model aspects.

c. The WES model does not provide a representation of intervisibility substantially better than that attainable in the combat simulations.

d. None of the models provides an adequate representation of intervisibility for general model applications in which representation of ground truth for a specific terrain site would be critical.

e. IUA modifications made for this study are appropriate to all versions and applications of the model.

f. DYNTACS modifications made for this study are approriate only in their general nature. Refinement is required prior to incorporation into the model for further applications.

APPENDIX A

MODEL BIBLIOGRAPHY

APPENDIX A

MODEL BIBLIOGRAPHY

A-1. PURPOSE. This bibliography lists model documentation that was available during the TETAM Model Verification study. The bibliography is listed in annotated form as an aid to future users of the models. This bibliography is not necessarily an exhaustive list of models documentation, but the major sources that will probably be available to a user are included.

A-2. CONTENTS. The appendix is organized into three annexes, one each for DYNTACS, IUA, and CARMONETTE.

a. Annex I--DYNTACS. Documentation of DYNTACS is extensive, and the bibliography is close to being exhaustive. DYNTACS documentation is unique in that much of the early research that fed into the model development is documented as well as the model itself. Thus, this is the only model for which the basis of most of the model representations can, with sufficient research, be found.

b. Annex II--IUA. Documentation of IUA is best described as spotty. Adequate information exists only on the mechanics of operating the computer programs. No meaningful documentation of the basis for most of the model formulations has been found. Model logic flow is reasonably documented in flow chart form. No discussion of the ramifications of various input values is available; however, data bases that have been used are available. It appears that users may tend to use these bases without question.

c. Annex III--CARMONETTE. A set of CARMONETTE documentation has recently been produced. This provides a reasonable picture of gross model logic, some of the model algorithms, and the mechanics of program operation and data preparation. Some discussion of the ramifications of certain data items is also included. No documented basis for the formulations contained in CARMONETTE has been found. Older CARMONETTE documentation has not been included in the bibliography since none has been found that is not redundant with the current documentation.

ANNEX A--I

ANNOTATED BIBLIOGRAPHY FOR DYNTACS

1. EARLY REPORTS OF BACKGROUND RESEARCH AND PRELIMINARY MODEL CONCEPTS.

a. Bussman, Dale R. Vibrations of a Multiwheeled Vehicle. Ohio State University, TR64-1, August 1964.
Equations describing tank movement on a terrain surface are presented.

b. Howland, Daniel and Bonder, Seth. The Tank Weapon System. Ohio State University, AR63-1, June 1963.
Describes a general model to guide and integrate research in the related areas of tank mobility, firepower, and survival.

c. _____. The Tank Weapon System. Ohio State University, PR64-1, December 1963.
Research in the areas of soft soil ability and cross country mobility is presented. The effects of cant on the accuracy of the tank main gun are reported.

d. _____. The Tank Weapon System. Ohio State University, AR64-1, June 1964.
Tank mobility in soft soil or rough terrain is discussed. Development of the target acquisition and fire control models is described.

e. _____. The Tank Weapon System. Ohio State University, AR65-1, June 1965.
Separate computer models are described for firing, mobility, hit probabilities, lethality, acquisition, and armor distribution.

f. Perloff, William H. Tank Mobility in Soft Soils. Ohio State University, TF65-2, June 1965.
Describes a computer program for soft soil mobility analysis. Covers track slippage and tank sinkage.

2. INITIAL INTEGRATED MODEL.

a. Howland, Daniel and Clark, Gordon. The Tank Weapon System. Ohio State University, AR66-1, June 1966.
The DYNTACS model is first referenced in this manual. A model overview is presented and a detailed description of five modules, (1) terrain and environment, (2) tactical decision, (3) intelligence, (4) movement, and (5) firing, is included.

b. _____. The Tank Weapon System. Ohio State University, AR66-2, December, 1966.
Equations describing the probability of detection and time to detection between an observer and tank are presented. A field experiment to validate those equations is reported. Microterrain and power spectral density

as used in the ground play of line of sight are discussed in detail. Detailed descriptions of concealment input parameters PCCS and YMAX are included. Soil strength and limiting speeds for tanks are also discussed.

3. THE BASIC GROUND MODEL NOW RECOGNIZED AS DYNTACS.

a. Bishop, Albert and Clark, Gordon. The Tank Weapon System. Ohio State University, AR69-2A, October 1969.
The first of two principal analyst manuals for users of the DYNTACS manual. Although these volumes describe in detail only the early version of the model known as DYNTACS, documentation of subsequent changes, improvements, and additions to the model describe only those parts of the model actually changed. Thus, the model descriptions in these two analyst manuals apply except where changed by subsequent volumes. This volume contains detailed descriptions of the DYNTACS submodels developed to simulate (1) terrain and environment, (2) communications, (3) intelligence (i.e., target acquisition), and (4) movement control.

b. _____. The Tank Weapon System. Ohio State University, AR69-2B, September, 1969.
The second of two principal analyst manuals for users of DYNTACS. The remaining five modules comprising the DYNTACS model are described: (1) the fire controller, (2) the movement model, (3) the firing model, (4) the minefield model, and (5) the indirect fire ballistic weapon (i.e., artillery) model.

c. _____. The Tank Weapon System. Ohio State University, AR69-4, September 1969.
This volume is appended to the AR69 series to provide the reader an overview of this early research and its principal results. Perusal of this volume should provide an appreciation of the significance of the original methodology produced and a measure of its potential usefulness in the reader's area of involvement. It is essentially an executive summary of the early work.

d. Bishop, Albert and Stollmack, Stephen. The Tank Weapon System. Ohio State University, AR68-1, September 1968.
This volume is valuable for its development of the detection process still used in DYNTACS. Chapters covering concepts of visual detection, contrast-dependent detection, probability for stationary targets, target contrast, and analysis of detection time data are included. Other less important areas discussed are availability, reliability, rough terrain, limiting speed, and a methodology for predicting overall dimensions and gross weight.

e. Clark, Gordon and Moss, Leslie. The Tank Weapon System. Ohio State University, AR69-3A, June 1969.

This volume describes the design and use of the DYNTACS computer program. Included in this volume are subroutine descriptions and flow charts, detailed descriptions of the data used in DYNTACS, a description of how data are prepared for input to DYNTACS, instructions for running the program, and sample outputs. Due to the fact that DYNTACS is no longer run on the same computer and extensive modifications have been made to the ground game, this volume is now of little value to most users.

f. _____. The Tank Weapon System. Ohio State University, AR69-3B, June 1969.

This volume, a continuation of AR69-3A described above, is now of little value to most model users.

4. DYNCOM--THE FIRST MAJOR EXPANSION.

a. Bishop, Daniel and Clark, Gordon. The Land Combat Model (DYNCOM). Ohio State University, FR-1, June 1969.

This volume describes the design principles of the DYNCOM model. DYNCOM is a modification and extension of the DYNTACS model. This volume only describes modifications and extensions to the DYNTACS model; therefore, 69-2A and 69-2B must be read prior to this volume to get the complete description of the DYNCOM model. Major additions documented in this volume are artillery, crew-served weapons, and beam-rider missile modules. Associated modifications to movement and firing tactics are also presented as well as a significant reworking of the communications model Additionally, research of some significance in modeling concealment, limited visibility conditions, and air/ground and ground/air visual detection are reported.

b. Clark, Gordon; Parry, Sam; Hutcherson, Don; Rheinfrank, John; and Petty, Gerald. Land Combat Model (DYNCOM) Programers Manual. Ohio State University, FR70-4A, April 1970.

This programers manual is a comprehensive list of input data commons, program descriptions, and flow charts of DYNCOM. Because FR70-4A and FR70-4B cover the complete model, it is not necessary to refer to earlier manuals. A cross reference listed in this manual between common areas and chapters which describe the model can be a valuable tool for preparing input data.

c. _____. Land Combat Model (DYNCOM) Programers Manual. Ohio State University, FR70-4B, April 1970.

This volume is a continuation of FR70-4A. The programers manual was broken into two volumes for ease of handling.

d. Clark, Gordon and Hutcherson, Don. Land Combat Model, The Aerial Platform Combat Operations Model. Ohio State University, FR71-3, May, 1971.

Documents the aerial platform module developed for DYNCOM. This module seems to have had limited acceptance, and the volume is not of great interest.

5. DYNTACS-X SECOND MAJOR EXPANSION.

a. Clark, Gordon and Parry, Samuel. Small Unit Combat Simulation (DYNTACS(X)) Counterbattery Fire Models. Ohio State University, FR70-1, July 1970.

The DYNTACS(X) version is an extension to the DYNCOM version. This volume reports the addition of a counterbattery fire module. As might be expected, it has no direct impact on the basic ground combat module.

b. Clark, Gordon et al. Small Unit Combat Simulation (DYNTACS(X) Air Defense Operations Model. Ohio State University, FR71-2A, March 1971.

As the title suggests, this volume documents inclusion of an air defense capability into the model. This differs from most other model expansions in that it could not be incorporated modularly but rather required extensive elaborations to the basic ground combat detection, firing, and fire control modules. A companion report (same authors, title, and date, issued as FR71-2B) contains flow charts and data layouts.

c. Clark, Gordon and Hutcherson, Don. Small Unit Combat Simulation (DYNTACS(X)) Fire Support Operation Models. Ohio State University, FR71-3A, October 1971.

This volume documents a revised aerial platform module, more accepted than the one developed for the DYNCOM version. The companion volume, FY71-3B, contains all flow charts and data blocks for DYNTACS(X).

ANNEX A--II

ANNOTATED BIBLIOGRAPHY FOR IUA

1. PREPARATION OF THE TERRAIN AND TACTICAL DATA BASE AND EXECUTION OF THE TERRAIN AND MOBILITY PROCESSORS.

a. US Army Combat Developments Command, Tank-Antitank and Assault Weapons Requirements Study, Phase III, Volume XIII, appendix III to annex L, AD849891L, December 1968.

The document contains the terrain and tactical analysis conducted during the TATAWS study for the IUA runs. It also provides several examples of the types of data needed to describe the terrain and the tactics played by attackers and defenders in the model.

b. ______, ______, Volume XXI, appendix VII to annex L, AD849897L, December 1968.

This report contains examples of the Red and Blue force compositions and tactical maneuvers for both forces used in the TATAWS runs. A complete listing of the critical range lines describing the model's tactical options for both attacker and defenders can also be found in the report.

2. DOCUMENTATION OF THE IUA COMBAT MODEL.

US Army Combat Developments Command, Tank-Antitank and Assault Weapons Requirements Study, Phase III, Volume XVIII, Tabs C and D of appendix V to annex L, AD849895L, December 1968.

The document contains flow diagrams of all programs and subroutines found in the IUA combat model. Flow diagrams of subroutines in the terrain and mobility models are not provided. Input card formats for the entire (terrain, mobility, and combat) data base are also provided.

3. GENERAL MODEL DOCUMENTATION.

a. US Army Combat Developments Command, Tank-Antitank and Assault Weapons, Phase III, Volume XVII, Tab B of appendix V to annex L, AD849894L, December 1968.

The document contains a table of all key model variable names and a description of their content. The variable names are grouped by subroutine for the terrain, mobility, combat, and postprocessor programs.

b. ______, ______, Volume XVI, Tab A of appendix V to annex L, AD849893L, December 1968.

The document contains a listing of all IUA programs. This includes the terrain processor, mobility processor, IUA combat model, output event processor, and the utility routines necessary to load the constant data deck.

c. Lockheed Missiles and Space Company, Instructions for Applying IUA Program to US Army CDC 3300, N-54-68-1, Sunnyvale, California, November 1968.

The document serves as an operator's manual, providing deck structures for exercising the model on the CDC 3300. The data base file structures used by the terrain processor, mobility processor, IUA combat model, and output event processor are also described.

d. US Army Combined Arms Combat Developments Activity, Procedure Guide for the Individual Unit Action (IUA) Model on the Fort Leavenworth Data Processing Installation CDC 6500 Computer System, Combat Operations Analysis Directorate Technical Report TR2-73, November 1973.

The document is an operator's manual, providing deck structure for exercising the model on the CDC 6500. It also contains a description of the input data card formats for the terrain processor, mobility processor, and IUA combat model.

4. DATA BASES FOR IUA COMBAT MODEL.

a. Goulet, B.N., Report on Support Provided by Army Material Systems Analysis Agency/Ballistic Research Laboratories for TATAWS III Computer Simulations (U), Army Material Systems Analysis Agency Technical Memorandum No. 20, Aberdeen Proving Ground, Maryland, January 1969, (SECRET).

Probabilities of hit and kill, and firing and flight times for weapons and rounds used in the TATAWS III IUA combat model runs can be found in this document. Much of the data is in the card format required by the IUA model.

b. Lockheed Missiles and Space Company, Report of Simulation Support for the Evaluation of Candidate Tank Considerations Using the Individual Unit Action (IUA) Simulation Model (U), LMSC-D009535, Sunnyvale, California, December 1972, CONFIDENTIAL.

The document contains probabilities of hit and kill for weapons and rounds used in the Tank Configuration study. Also included are distributions describing the time required by crews to detect a target. All data are in the format required by the IUA model.

ANNEX A--III

ANNOTATED BIBLIOGRAPHY FOR CARMONETTE

1. General Research Corporation, CARMONETTE, Volume I--General Description, McLean, Virginia, 1974.
This is an executive level overview of the model. It also contains, in the space of a dozen pages, the only available discussion of the mathematical basis of the model.

2. _____, CARMONETTE, Volume II--Data Preparation and Output Guide, McLean, Virginia, 1974.
This volume is oriented to the individuals responsible for developing CARMONETTE input data. Coding forms and instructions for preparing the data are included, with illustrative examples. Discussions of the ramifications of selected data items, many of which are of a subjective or aggregated nature, are also included.

3. _____, CARMONETTE, Volume III--Technical Documentation, McLean, Virginia, 1974.
This volume is programer oriented. It documents detailed logical flow, data layout within the computer, and mechanical operating procedures.

APPENDIX B

SENSITIVITY ANALYSIS OF COMPARISON VARIABLES

APPENDIX B

SENSITIVITY ANALYSIS OF COMPARISON VARIABLES

B-1. GENERAL. Intervisibility comparisons for TETAM depend upon the use of variables derived from the fundamental data collected in CDEC Experiment 11.8. These fundamental data are subject to some level of error, but a statistically sound means to measure the error inherent in the data is not known. Sensitivity testing was conducted to provide an indication of the probable stability of derived variables and, by implication, conclusions based upon such variables in light of the possible error in the fundamental data.

B-2. APPROACH.

a. Fundamental Data. The fundamental data from Experiment 11.8 of primary concern are the determined existence or lack of intervisibility from a viewing point in the field to an ATM target panel. In Experiment 11.8, such a determination was made from two observer heights at approximately 2,000 viewing points to each of 36 target panels for each of three trial conditions (termed Site A Rapid Approach, Site A Covered and Concealed Approach, and Site B). Based on the quality control procedures followed in the field, the CDEC final experimentation report states that "at the very worst, 5.0 percent of the data could be in error" (reference 1d, page A-1-13). Of secondary interest to this analysis is the reported nature of line-of-sight blockages. No direct quality control of the blockage data was attempted in the field experiment.

b. Derived Variables. The derived variables investigated in this analysis are, for each of the three trial conditions: the overall probability of line of sight, the number of intervisibility segments, and the mean length of an intervisibility segment. An intervisibility segment is the space between consecutive viewing points for which intervisibility to a single target exists. Intervisibility is assumed to continue without interruption between such viewing points. For segment length computations, a change of intervisibility status between two points is assumed to take place midway between the points. These variables, or trivial variations thereof, have been used by past studies including the CDEC analysis of Experiment 11.8 results in an attempt to describe terrain on the basis of a few descriptors.

c. Sensitivity Treatments. Four simplistic treatments, discussed below, were applied to the fundamental data for the purpose of viewing the sensitivity of the derived variables to changes in the fundamental data. Variations similar to those of the first two treatments might relect errors that actually took place in the field. Objectives analysis or error modes that actually occurred in the field would have to be based on the quality control data collected in the field which, unfortunately, were discarded in the field after serving their basic purpose.

(1) Random 5 percent treatment. For each "yes" and "no" determination of line-of-sight existence in the data base, a uniformly distributed random number on the unit interval was drawn and the determination changed if the random number exceeded 0.95. This is equivalent to changing 5 percent of the determinations, randomly selected.

(2) Selective 5 percent treatment. For each "no" determination in the data base, a uniform random number was drawn from the unit interval and the determination changed to "yes" if the random number exceeded 0.95. This is equivalent to changing 5 percent of the "no" determinations, randomly selected. Since the "no" determinations constitute 71 to 82 percent of the original data (depending on which trial condition is considered), this treatment changes 3.5 to 4 percent of the data. This may reflect field error to the extent that a missed determination is, from a subjective review of the experiment, the most likely error. There is, however, no basis for any quantified error rate or for applying such error randomly over the data.

(3) Flicker treatment. For this treatment, a line-of-sight segment is considered interrupted only if two or more consecutive determinations of no line of sight are made for a given ATM panel and approach path. Thus, isolated "no" determinations were changed to "yes" for this treatment. This is a highly selective treatment resulting in changes to well under 2 percent of the fundamental data. The treatment is intended to illustrate the critical nature of a selected, but small, portion of the data. It would be unduly pessimistic to imply that such a highly patterned error mode in fact took place in the field.

(4) No vegetation treatment. This treatment consisted of changing each "no" determination for which the nature of blockage was reported as being vegetation to a "yes" determination. This treatment amounts to a massive modification of the data base, resulting in changes to about one-third of the data for Site A conditions and 80 percent of the data for Site B. No such extreme error rate in the field data should be inferred. The threatment provides a comparison of the effects of a massive data change as opposed to the relatively small changes of the other treatments.

B-3. RESULTS OF THE ANALYSIS. The results of the sensitivity analysis are presented in tables B-1 to B-3 and are summarized below. Resulting derived variables are presented for the high-high and low-low combinations of target panel and observer height. Values of the derived variables for intermediate height combinations fall between the presented values, as would be expected.

a. Overall P_{LOS}. The overall probability of line of sight is relatively stable under all except the "no vegetation" treatment. This is to be expected from the nature of the treatments. Where less than 5 percent of the data are changed, it would be impossible for P_{LOS} to change by

Table B-1. Sensitivity Analysis, Site A, Rapid Approach

	Number of Segments		Mean Segment Length (m)		Overall P_{LOS}	
	L*	H*	L*	H*	L*	H*
Original data	2961	2943	153	180	.25	.29
Random 5 percent treatment	5783	5001	86	95	.28	.31
Selective 5 percent treatment	5159	5104	100	113	.29	.32
Flicker treatment	2170	2163	221	254	.27	.30
No vegetation treatment	4553	4042	226	274	.57	.62

*L = Low observer and low target panel.
H = High observer and high target panel.

Table B-2. Sensitivity Analysis, Site A, Covered Approach

	Number of Segments		Mean Segment Length (m)		Overall P_{LOS}	
	L*	H*	L*	H*	L*	H*
Original data	2888	3155	136	145	.22	.25
Random 5 percent treatment	5750	6036	77	81	.25	.27
Selective 5 percent treatment	5333	5420	86	95	.26	.29
Flicker treatment	2115	2267	194	211	.23	.26
No vegetation treatment	5129	4818	217	248	.62	.67

*L = Low observer and low target panel.
H = High observer and high target panel.

Table B-3. Sensitivity Analysis, Site B

	Number of Segments		Mean Segment Length (m)		Overall P_{LOS}	
	L*	H*	L*	H*	L*	H*
Original data	2476	2807	89	92	.16	.18
Random 5 percent treatment	4759	5051	56	59	.19	.21
Selective 5 percent treatment	4566	4765	61	65	.20	.22
Flicker treatment	1697	1855	141	152	.17	.20
No vegetation treatment	585	528	2303	2569	.96	.97

*L = Low observer and low target panel.
H = High observer and high target panel.

more than 5 percentage points. In fact, for all except the random 5 percent treatment, the change in P_{LOS} is a direct reflection of the amount of data changed by the treatment. For example, where P_{LOS} changes from 0.29 to 0.32 (selective 5 percent treatment, Site A Rapid Approach, high-high height combination) this is a direct indication that 3 percent of the data were changed to a "yes" determination. The effect of the "no vegetation" treatment on overall P_{LOS} is indicative of the degree to which vegetation played a role in the field determinations. For example, if the original data contain a P_{LOS} = 0.29 and the "no vegetation" results in P_{LOS} = 0.62 (Site A, Rapid Approach, high-high combination) it can be inferred that the remaining 38 percent of the data must contain landform blockages ("cultural" and "unknown" masks were rarely reported), and 0.62 - .29 = 0.33, or 33 percent of the blockage on the site is caused by vegetation; that is, the effects of vegetation and landform are approximately equal over the site. Vegetation clearly is the dominant factor on Site B.

b. Number of Segments. Both the random 5 percent and the selective 5 percent treatments produce a marked increase in the number of intervisibility segments. The trend was to be expected, since the data tend to appear in "strings" of intervisibility or nonintervisibility; and a random selection of changes to be made would tend to break up these strings. The extent of the change is noteworthy. Changes to at most 5 percent of the fundamental data increase the number of segments by at least 70 percent and, in some cases, essentially double the number of segments. The effect of the flicker treatment is totally predictable since each changed determination will connect two segments, resulting in a decrease of one segment. Thus, the decrease in number of segments indicates the exact number of changes made with this treatment.

c. Mean Segment Length. The effects of the various treatments on mean segment length are, in general, corollary to their effects on the number of segments. The marked increase in number of segments with the random 5 percent and selective 5 percent treatments indicates that both treatments are introducing a large number of isolated "yes" stakes, each of which would result in a 25-meter segment. Additionally, the 5 percent random treatment must be breaking up a number of segments into two shorter pieces. The net result of each of these must be to pull down mean segment length. Every change introduced with the flicker treatment, on the other hand, will join two original segments into one longer segment, pushing up the mean segment length.

B-4. DISCUSSION.

a. The most striking result of this analysis is the potentially extreme sensitivity of variables describing intervisibility segments to what would, in most field experiment situations, be considered an acceptable error rate. This extreme sensitivity appears to be related more strongly to the pattern, or lack of pattern, with which errors could appear in the data rather than to the actual number of errors. This point is further illustrated by the data in table B-4, in which the mean segment lengths for the Site A, Rapid Approach trial are shown for all height combinations under the flicker and no vegetation treatment. In this case, the flicker treatment involves a change to slightly over 1 percent of the data, while the no vegetation treatment involves a change to approximately one-third of the data. Considering this difference, the resulting mean segment lengths are remarkable similar.

Table B-4. Mean Segment Length (Meters) for Selected Treatments, Site A-Rapid Approach

Observer Height	Target Panel	Original Data	Flicker Treatment	No Vegetation Treatment
Low	Low	153	221	226
Low	Mid	158	226	230
Low	High	159	226	230
High	Low	166	241	267
High	Mid	173	249	273
High	High	180	254	274

b. It must be reemphasized that the extent and patterns of error actually present in the fundamental data collected in Experiment 11.8 are unknown and that there is no objective means to estimating this information, short of reexecution of the experiment. Thus, while this analysis provides an indication of the effect some hypothetical error patterns could have on the derived variables, actual error trends in the available data remain open to conjecture.

B-5. CONCLUSIONS.

a. Intervisibility segment descriptors can be highly sensitive to relatively low error rates within the fundamental data used to develop these descriptors.

b. The degree of sensitivity of intervisibility segment descriptors to errors in the fundamental data depends primarily on the patterns in which these errors may occur, not on the relative number of errors.

c. Probability of line-of-sight measures are not highly sensitive to moderate error rates in the fundamental data.

d. The degree of sensitivity of P_{LOS} measures to errors in the fundamental data depends upon the amount of error in the data. Error patterns are of relatively minor importance in determining this level of sensitivity.

APPENDIX C

NOTES TO REVISED DYNTACS INTERVISIBILITY

APPENDIX C

NOTES TO REVISED DYNTACS INTERVISIBILITY

C-1. PURPOSE. The purpose of this appendix is to describe the stochastic treatment of vegetation introduced to DYNTACS intervisibility logic. The discussion is oriented to a programmer familiar with DYNTACS routines and logic.

C-2. MATHEMATICAL BASIS.

a. Problem. Determine whether a straight line segment will pass uninterrupted through a DYNTACS feature containing vegetation.

b. Representation of Vegetation. Vegetation within a given feature is assumed to be composed of randomly distributed homogeneous "clumps" (trees or bushes). Each vegetation clump is represented as an opaque cylinder of height T and radius R, and these clumps occur with density D in the feature.

c. Basic Model. A straight line sement of arbitrary length L, entirely enclosed within the feature, will be uninterrupted by any clumps with the probability:

$$P_O = e^{-2LRD}$$

This comes from consideration of the situation illustrated in figure C-1. If the line is enclosed by a box of length L and width 2R, as illustrated, the line will be interrupted by any circle of radius R whose center lies within the box. Using the Poisson distribution, with the density of circles or clumps equal to D, then the probability of no clump centers lying within the box (or any enclosed area of size 2RL) is P_O as indicated below.

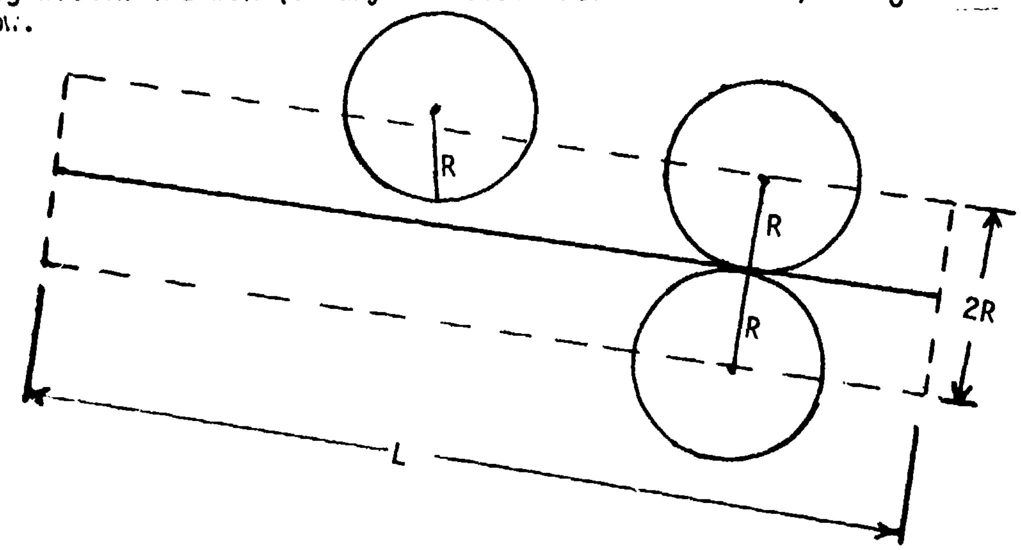


Figure C-1. Basic Scheme for Random Vegetation

C-3. INCORPORATION TO DYNTACS.

a. Data Areas. COMMON BLOCK DCON should be defined to contain the values of T, R, and D for each feature class. Additionally, COMMON HTREE should be set to the maximum value of T over all feature classes.

b. Routine TREES. The original version of TREES returned the value HTREE if a point in question was contained in a forest feature. The routine should be changed to return tree height T of the appropriate feature if a point in question lies in the feature and a random draw is greater than the value of P_0 computed as above. Calculation of P_0 requires the values of R and D associated with the feature and a value L passed in the calling sequence.

c. Routine LOSCMP. This is the basic line of sight determining routine and the only routine that calls TREES. This routine scans a segment in three passes over three sets of plane departure points. The logic should be revised to call TREES only on scanning the set of points for which distance between points is a minimum and that distance should be passed to routine TREES as the length 2. The three interpoint distances are found in array DF and were established upon the call to routine POPSET.

C-4. LIMITATIONS. The incorporation outlined above provides an approximation of the basic model developed. The limitations, which could be removed with more complicated programming, are noted below.

a. Each plane departure point within a feature generates a "box" of area 2RL. There is no guarantee that the box lies entirely in the feature. This edge effect is minimized by selecting the set of departure points with minimum interpoint distance.

b. The logic is inexact for overlapping features with different vegetation parameters.

C-5. DATA DEVELOPMENT. Procedures used in TETAM for developing the required vegetation data are outlined below. These are open to improvement. Materials used for TETAM were a set of aerial photographs of the region and a 1:25,000 map.

a. Step 1. Identify on the aerial photograph the features to be coded. These should be circles or parallelograms with essentially homogeneous vegetation. Homogeneity was determined judgmentally from the photograph.

b. Step 2. Determine map coordinates of the feature identified in Step 1. This was accomplished for TETAM by locating significant reference points on both the aerial photographs and map and estimating feature coordinates by relative position of the features to the reference points. Reference points can be roads, road junctions, stream lines, etc. The

error involved in this step can be much reduced if an orthophotomap of the region can be obtained (these were used in TETAM) since the vegetation areas show up with reasonable clarity on these maps and less dependence is put on the reference points. This step could be greatly improved with good stereopairs of the area and the proper stereoviewing equipment.

c. Step 3. Determine density for each feature by calculating its area (from map coordinates) and counting the trees (on the photographs) in the feature. Density is number of trees divided by area.

d. Step 4. Estimate tree height and width in each feature. For TETAM this was accomplished by recourse to vegetation overlays developed by Waterways Experiment Station, to oblique photographs of the region, and to the analyst's familiarity with the region. This may be the most serious problem for general applications. Proper stereo material should be valuable.

e. Step 5. To arrive at a reasonably small number of feature categories, combine those that are similar. This was a judgmental step in TETAM. The guiding criterion was the product of tree width and density, which enters into the model. As long as this product is reasonably constant and heights are similar, features can be said to fall in the same category.

APPENDIX D

REFERENCES